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ıoor Air Quality Management for ıerations and Maintenance Personnel

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There is a growing body of information related to facility indoor air quality (IAQ) and its affect on the health and productivity of building occupants. Indoor air pollution can increase employee absenteeism and reduce productivity. Poor IAQ may be a result of poor building or ventilation design, improper maintenance, or inappropriate energy conservation strategies.

To help ensure the health, welfare, and productivity of Army personnel and the performance of Army facilities, installation operations and maintenance (O&M) personnel need access to relevant and useful information about IAQ issues. This report includes background information for O&M managers and staff, an installation-level IAQ management plan, and practical O&M procedures for correcting the problems that most commonly lead to IAQ-related complaints.

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FOREWORD

This study was conducted for the U.S. Army Engineering and Housing Support Center (USAEHSC) under project 62784AT41, "Military Facilities Engineering Technology"; Task Area SA; Work Unit AXO, "Human Habitability Requirements/Indoor Air Quality." The USAEHSC technical monitor was Mr. Chris Irby, CEHSC-F-UM.

This research was performed by the Facility Systems Division (FS) of the U.S. Army Construction Engineering Research Laboratory (USACERL) in conjunction with Ben J. Sliwinski, President, Research Associates of Urbana, IL. Consultation and review were provided by the USACERL Environmental Engineering Team, Environmental Division, and the Energy Design and Management Team, Energy and Utility Systems Division. Dr. Michael J. O'Connor is Chief of USACERL-FS. The USACERL technical editor was Gordon L. Cohen, Information Management Office.

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CONTENTS

CONTENTS (Cont'd)

TABLES

FIGURES

INDOOR AIR QUALITY MANAGEMENT FOR OPERATIONS AND MAINTENANCE PERSONNEL

1 INTRODUCTION

Background

It has been estimated that many people spend up to 90 percent of their time indoors. This, and the growing body of evidence linking environmental factors to human health, has naturally led to concern about indoor air quality (IAQ). Items in the news—notably the outbreak of legionnaires disease in 1976—focused widespread public attention on the IAQ issue. Since then, asbestos, radon gas, and volatile organic compounds (VOCs) have also entered public awareness as indoor pollutants that can seriously threaten health and wellbeing.

IAQ problems have been divided into two categories: Sick Building Syndrome (SBS) and Building Related Illness (BRI). SBS is suspected when more than 20 percent of a building's occupants complain of symptoms (i.e., headache, irritation of eyes, nose, throat, or skin, dry cough, fatigue, dizziness, nausea, or difficulty in concentrating), the cause of the symptoms is not obvious, and the symptoms disappear after leaving the building. BRI is suspected when occupant exposure to indoor contaminants results in a clinically defined illness or infirmity that lingers long after the person leaves the building. An important distinction between SBS and BRI is that SBS is not necessarily tied to specific contaminants. Better ventilation or maintenance may alleviate SBS, but in the case of BRI, it is usually necessary to determine a specific source before a solution can be implemented.

All IAQ problems, whether SBS or BRI, can have a strong negative effect on individual productivity and absenteeism, can impair the performance of sensitive equipment[1] and, in some cases, can cause debilitating or life-threatening illness. For example, a recent study indicated that the risk of acute respiratory disease was 45 percent higher in modern barracks with low ventilation rates than in older barracks with higher ventilation rates.[2]

It has been estimated that in 75 percent of the cases maintenance deficiencies are a cause of IAQ problems.[3] Maintenance problems related to building structure, heating, ventilating, and air conditioning (HVAC) systems, general housekeeping, and the lack of a comprehensive maintenance plan have all been identified as causes of poor IAQ. Operational problems include improper or inadequate control of HVAC

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[1] C.J. Weschler et al., "Comparison of Effects of Ventilation, Filtration, and Outdoor Air on Indoor Air at Telephone Office Buildings," *Design and Protocol Monitoring for Indoor Air Quality*, ASTM STP 1002, (American Society for Testing and Materials [ASTM], 1989).

[2] John F. Brundage et al., "Building Associated Risk of Febrile Acute Respiratory Diseases in Army Trainees," *Journal of the American Medical Association*, Vol 259 (April 1988).

[3] D.R. Rask and C.A. Lane, "Resolution of the Sick Building Syndrome: Part II, Maintenance," *IAQ89 The Human Equation: Health and Comfort* (American Society of Heating, Refrigerating, and Air-Conditioning Engineers [ASHRAE], 1989).

systems, changes in use and occupancy levels beyond those allowed for in the building design, and the introduction of new building material or furnishings that produce indoor air pollutants.

Because in many cases lower ventilation rates have been identified as the source of IAQ problems, and, because in some of these cases ventilation was reduced as an energy conservation measure, there has been a reevaluation of the tradeoffs between energy conservation and occupant productivity and health. While hard data are not abundant, it appears there are cases in which energy conservation activities may cause a net economic loss (through lost productivity) rather than the intended savings.

One of the Army's high priorities is ensuring the safety, health, and wellbeing of soldiers and civilian employees. Furthermore, the increasing scarcity of resources requires the Army to take every feasible step to ensure the productivity of workers while conserving energy and generally optimizing the performance of Army facilities. The U.S. Army Construction Engineering Research Laboratory (USACERL) has been assigned the task of compiling relevant information about IAQ problems for use by Army operations and maintenance (O&M) personnel at both the management and hands-on levels.

Objective

The objective of this study was to provide O&M personnel with useful background information on IAQ, a general installation IAQ management plan, and basic preventive methods for use in representative Army facilities.

Approach

Much of this report was compiled through a literature search, with a concentration on relevant Army manuals and publications. Other material is based on the training and experience of the authors as well as consultation with other professionals in the field.

Scope

This report does not cover all mechanical system types and permutations. The systems discussed were chosen for their relevance and frequency of use in Army facilities.

Mode of Technology Transfer

It is recommended that information in this report be transferred to the field through workshops and short training courses. On-site demonstrations at representative Army facilities would also be appropriate and useful.

2 CAUSES OF UNACCEPTABLE IAQ IN BUILDINGS

A recent paper documents the experience of the National Institute for Occupational Safety and Health (NIOSH) in conducting evaluations of IAQ problems.[4] Between 1978 and 1984, NIOSH conducted 446 IAQ investigations. The majority of the investigations were conducted in Government and private-sector office buildings (367), while the remainder included schools, colleges, and healthcare facilities. Although many IAQ problems had multiple causes, NIOSH was able to classify the results of their evaluations according to the primary type of problem found. NIOSH found that building material was the primary problem source in 3 percent of the cases; microbial contaminants were the source in 5 percent; outside contamination was the source in 11 percent; inside contamination was the problem source in 17 percent; and, inadequate ventilation was the problem source in 52 percent of the cases. In 12 percent of the cases no specific problem source could be identified. Each source is discussed in the following sections.

Building Materials Contamination

Formaldehyde outgassing from urea-formaldehyde foam insulation, particle board, plywood, and certain glues and adhesives were significant sources of this contamination. Other problem building materials included fibrous glass materials, various organic solvents from glues and adhesives, and acetic acid used as a curing agent in silicone caulking.

Microbiological Contamination

Microbial contaminants can result in a potentially serious condition known as hypersensitivity pneumonitis. This respiratory problem can be caused by bacteria, fungi, protozoa, and microbial products that may originate in ventilation system components. In the NIOSH investigations a common source of microbial contamination was water damage to carpets or furnishings. Standing water in ventilation system components was also a problem.

Outside Contamination

Contamination from sources outside the building was determined to be a major problem in 11 percent of the NIOSH investigations. Problems with motor vehicle exhaust, boiler gases, and previously exhausted air occurred as a result of improperly located exhaust and intake vents or periodic changes in wind conditions. Other outside contamination problems included contaminants from construction or renovation, such as dust, asphalt vapors, and solvents. Gasoline fumes infiltrating a basement or sewer system were sometimes a problem, caused by leaks in nearby service station underground storage tanks (USTs). One of the most common sources of outside contamination was carbon monoxide fumes from basement parking garages.

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[4] R.W. Gorman and K.M. Wallingford, "The NIOSH Approach to Conducting Indoor Air Quality Investigations in Office Buildings," *Design and Protocol for Monitoring Indoor Air Quality*, ASTM STP 1002 (ASTM, 1989).

Inside Contamination

Contamination generated by sources inside the building was a major problem in 17 percent of the NIOSH investigations. Copying machines were often found to be a significant source; examples included methyl alcohol from spirit duplicators, butyl methacrylate from signature machines, and ammonia and acetic acid from blueprint copiers. Other inside contamination problems included improperly applied pesticides, boiler additives such as diethyl ethanolamine, improperly diluted cleaning agents such as rug shampoo, tobacco smoke of all kinds, and combustion gases from cafeterias and laboratories (Other possible sources not indicated by NIOSH include formaldehyde vapors from carpet and furniture, and other VOCs from personal care products.)

Inadequate Ventilation

In 52 percent of the NIOSH investigations—a clear majority of the cases—building ventilation was found to be inadequate. Problems included inadequate outdoor air supplied to the space, poor air distribution and mixing, and filtration problems due to improper maintenance. In some cases, energy consumption measures resulted in reduced ventilation and poor IAQ. Problems related to energy conservation are discussed below. The discussion is not intended to imply that energy conservation measures should be avoided, but that possible IAQ problems should be addressed when implementing energy retrofits.

Reduced Ventilation Rate

Reduction in the amount of outside air drawn into a building significantly reduces the amount of energy consumed by the HVAC system by reducing both sensible and latent loads. This reduction in air intake, however, can result in the buildup of air contaminants within the building. This problem is made worse when filtering systems are poorly maintained. Occupants may experience discomforts ranging from a sense of "stuffiness" to SBS or BRI.

Use of Variable Air Volume HVAC Systems

Variable air volume (VAV) systems respond to changes in zone loads by varying the amount of conditioned air supplied. Under conditions of reduced load, air supply to the zone is correspondingly reduced, producing low ventilation levels and potential for IAQ problems. Occupants may experience a range of discomfort. Induction VAV systems may also have a tendency to create isolated concentrations of air contaminants within a single zone since these systems recirculate zone air returned through the ceiling plenum. Zone air contamination problems may be aggravated since no ceiling plenum air filtering is provided.

Reduction in Heating Thermostat Settings

Lower thermostat settings during the heating season will result in lower zone loads. For VAV systems this will result in less air supplied to the zone. Condensation of humidified air may occur in supply ducts if air supply temperatures become too low. The resultant condensate can provide habitat for molds and bacteria. Occupants may experience thermal discomfort and effects of low ventilation rates. Thermal discomfort may make occupants more vulnerable to indoor air contaminants.

Increase in Cooling Thermostat Settings

Higher thermostat settings during the cooling season result in lower zone loads and a reduction in air supplied by VAV systems. Increased humidity may result in many HVAC system types. The overall result is lower ventilation, increased concentration of indoor air contaminants, and the potential for microorganism growth due to higher temperatures and humidities. Occupants may experience discomfort due to high temperature and humidity, concentrations of indoor air contaminants, and reduced ventilation. Discomfort from temperature and humidity may sensitize occupants to general IAQ problems.

Reduction in Lighting Levels

Electrical energy savings can be obtained by reducing lighting levels. In some cases this can affect IAQ. Heat generated by lighting systems is considered in the design of both heating and cooling systems. When lighting loads are diminished, this heat load is correspondingly decreased. With VAV systems, reduction in lighting loads may sufficiently diminish zone loads to result in low ventilation rates. Also, with reductions in lighting occupants may experience headaches and eyestrain, which may heighten adverse responses to IAQ problems.

Reduction in Infiltration Rate

Activities such as weatherstripping, caulking, and window replacement reduce energy consumption by reducing outside air infiltration. In some cases IAQ problems may occur due to insufficient levels of outside air if the mechanical ventilation system is not performing properly. Short term IAQ problems may occur due to outgassing of contaminants from some sealing materials.

Increased Building Envelope Insulation

Increased envelope insulation results in reduced loads through reductions in heat losses or gains. While in most cases improved occupant comfort results, IAQ problems can sometimes result from outgassing of insulation materials and reduced ventilation by VAV systems under low-load conditions.

Unknown Source

In 12 percent of the NIOSH studies, no specific source for the IAQ complaint could be identified. This may often occur due to the multifactorial nature of some IAQ problems; no single source may be prominent enough to be specifically identified, but the combination of several small problems may cause unacceptable IAQ.

3 SOURCES OF INDOOR AIR CONTAMINANTS

Environmental Tobacco Smoke

Environmental tobacco smoke (ETS) is the most common and most frequently recognized indoor air contaminant. Tobacco smoke degrades IAQ by introducing odors, potentially harmful gases, and particulates. Tobacco smoke is a complex mixture of several hundred substances including irritants (aldehydes), toxic chemicals (carbon monoxide), and carcinogens (benzo[a]-pyrenes, tars, etc.). More than 50 chemicals in tobacco smoke are known to cause adverse health effects; 12 are known or suspected carcinogens. In the office environment, the primary complaints about ETS are irritation to the eyes and upper respiratory tract, usually caused by the aldehydes in the smoke.

It has been estimated that 63 percent of nonsmokers are exposed to tobacco smoke at work. The ambient concentrations of second-hand smoke are much lower than the concentrations to which active smokers are exposed, but it has been calculated that in an office where many people smoke, second-hand exposure is equivalent to one to five cigarettes per day.[5] Data from one study indicated that an increase of 1 $\mu g/m^3$ in fine particulate from ETS is associated with a 3 percent excess in acute respiratory disease.[6] Another study indicates that IAQ complaints are more frequent among smoking men than nonsmoking men.[7]

Most Government office facilities now restrict smoking to specific areas within the building. Care should be taken in selecting these areas, with consideration given to the relationship between the smoking area and the building HVAC system. If feasible, smoking should be restricted to zones whose air flow is not recirculated to nonsmoking zones.

Asbestos

Airborne asbestos fiber has been linked to cancer of the lungs and abdomen. While asbestos may be found in many building materials, the hazard is fortunately not severe unless the asbestos is "friable" (crumbly or brittle). Asbestos materials that are inherently friable, such as those that are sprayed or troweled on, have been banned by the U.S. Environmental Protection Agency (EPA) since 1970. By 1996, most asbestos-containing building materials in the United States are scheduled to be banned.[8]

Asbestos may be found in numerous building materials. Examples include vinyl asbestos tile, roofing felts, and acoustical, fireproofing, and thermal insulation, including pipe insulation. Because of the severe health hazard posed by inhalation of asbestos fibers, O&M personnel should never disturb asbestos-containing materials. This may require careful review of existing O&M procedures. Education of

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[5] R. House, *Report to the (Canadian) Ministry of Labour, The Health Effects of Involuntary Exposure to Tobacco Smoke* (June, 1985).

[6] B.D. Ostro, "The Effects of Environmental Tobacco Smoke on Acute Respiratory Conditions," *IAQ89 The Human Equation: Health and Comfort* (ASHRAE, 1989).

[7] M.J. Hodgson and P. Collop, "Symptoms and the Micro-Environment In the Sick Building Syndrome: A Pilot Study," *IAQ89 The Human Equation: Health and Comfort* (ASHRAE, 1989).

[8] *Indoor Air Quality Environmental Information Handbook: Building System Characteristics*, DOE/EV/10450-H1 (U.S. Department of Energy [DOE], 1987).

management, O&M staff, and others who may come in contact with asbestos will minimize the risk of accidental exposure or release of fibers.

If it becomes necessary to disturb asbestos-containing materials, or, if the decision is made to remove such material, the services of a qualified asbestos removal firm should be employed. Full-scale asbestos removal requires sophisticated procedures including isolation of the building HVAC system, evacuation of the contaminated space, and stringent containment, decontamination, and disposal procedures.[9]

Microorganisms and Airborne Biological Sources

Contamination from microbial and other biological sources can contribute to BRI and SBS. Where unsanitary conditions develop in HVAC equipment or interior zones, biological growths can develop to the extent of aggravating allergies or causing infectious illness. Some microorganisms, such as bacteria and fungi, multiply more rapidly in elevated humidity.

Microbial evaluation remains one of the least precise areas of IAQ assessment. A broad array of algae, protozoans, fungi, and bacteria may be present within buildings. A variety of common environmental fungi and bacteria may be isolated from indoor air samples with no clear distinction between background and problem concentrations.[10] Because presently there are no conclusive data on problem concentration levels, limited guidance can be provided here. Table 1 shows data on biological contaminant levels, measured in colony-forming units (CFUs), found in a residence reporting no IAQ-related complaints. The data in Table 1 illustrate the levels of various microorganisms that have been found in a residence without producing discernible adverse impacts.

The primary source of bacteria indoors is the human body.[11] A major source is the respiratory system. A less obvious source is the microscopic scales of skin that people normally shed. It has been determined that millions of skin scales are shed per minute per person, with an average of four viable bacteria per scale. Evidence also indicates that a number of viruses that infect humans can be transmitted by the air (Table 2).

Legionnaires disease, a potentially fatal lung infection, has been associated with infiltration of aerosols from exterior sources such as cooling towers. The most common means of spreading legionnaires disease involves air-cooling equipment that becomes contaminated and produces concentrated bacterial aerosols. A less severe form of the disease from the same microorganism, known as "Pontiac fever," causes fever, headache, muscle pain, and malaise.[12]

Similar disease-causing microorganisms can also be disseminated via hot tubs, whirlpools, and by air conditioning and humidifying equipment. Cool-mist vaporizers and nebulizers can produce highly contaminated airborne droplets since most such units are contaminated with bacteria. Evaporative

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[9] B. Watkins, "Managing Asbestos Abatement," *Building Operating Management* (January 1990).

[10] E.N. Light et al., "Abatement of Aspergillus Niger Contamination in a Library," *IAQ89 The Human Equation: Health and Comfort* (ASHRAE, 1989).

[11] DOE/EV/10450-H1.

[12] DOE/EV/10450-H1.

Table 1

Summary Results of Viable Airborne Microorganism Monitoring (CFU/m^3)*

Genera	Average Indoor	Average Outdoor	Range Indoor	Range Outdoor
Winter:				
Bacteria				
Bacillus	820	260	33-3300	0-1700
Micrococcus	70	25	0-380	0-580
Staphylococcus	250	20	0-1500	0-280
Total	**1140**	**305**		
Fungi				
Penicillium	80	20	0-3000	0-350
Aspergillus	45	15	0-450	0-270
Other (Mucor, Fusarium, Candida)	90	25	0-1300	0-220
Total	**215**	**65**		
Summer:				
Bacteria				
Bacillus	1270	600	0-6000	0-6200
Micrococcus	70	15	0-630	0-330
Staphylococcus	140	30	0-5500	0-470
Total	**1480**	**645**		
Fungi				
Penicillium	870	1200	0-6200	0-8000
Aspergillus	480	340	0-3000	0-5400
Other (Mucor, Fusarium, Candida)	140	100	0-1350	0-730
Total	**1490**	**1640**		

* Source: A.R. Hawthorne et. al., "Case Study: Multipollutant Indoor Air Quality Study of 300 Homes in Kingston/Harriman Tennessee," *Design and Protocol for Monitoring Indoor Air Quality*, ASTM STP 1002 (ASTM, 1989).

Table 2

Human Viral Diseases Transmitted by Air

Smallpox	Influenza
Chicken pox	Adenovirus 4 and 7
Measles	Coxsackie A21
Rubella	Lymphocytic Choriomeningitis

humidifiers, although also contaminated with bacteria, are less likely to produce bacteria laden vapors.[13] Other sources of airborne biological pollutants include self-defrosting refrigerators, clothes dryers vented into living space, flush toilets, shower heads, and ice machines.

Many biological materials, including pollen, fungi, insects, and algae, can cause allergic reactions in building occupants. Allergic reactions can occur on the skin, in the nose, airways, and lungs. The most common respiratory allergic reactions are rhinitis, affecting about 15 percent of the population, and asthma, affecting 3 to 5 percent.[14] Hypersensitivity pneumonitis is a less common disease, but it is potentially serious because, if the diagnosis is not made early and exposure continues, irreversible lung damage can occur.

Specific sources of bioaerosols implicated as causes of IAQ problems include HVAC components using water spray systems, humidifiers that use recirculated water, cool-mist vaporizers, fan-coil unit drip pans, and wet or previously wet carpeting or furnishings.[15]

VOCs

VOCs include a large number of carbon-based chemicals. In a study that sampled air in 25 office buildings, it was found that the ratio of indoor total VOCs to outdoor VOCs varied from 4:1 to 16:1 under conditions of minimum ventilation, to less than 2:1 when a large amount of outside air was supplied.[16] On the average, the indoor concentration of VOCs was three times higher than outdoors, indicating that the source of the chemicals is probably indoors.

[13] DOE/EV/10450-H1.

[14] DOE/EV/10450-H1.

[15] W.A. Turner et al., "Workshop: Data Collection Aspects of Building Investigations," *Design and Protocol for Monitoring Indoor Air Quality*, ASTM STP 1002 (ASTM, 1989).

[16] P.R. Morey and B.A. Jenkins, "What Are Typical Concentrations of Fungi, Total Volatile Organic Compounds, and Nitrogen Dioxide in an Office Environment?" *IAQ89 The Human Equation: Health and Comfort* (ASHRAE, 1989).

Formaldehyde is a common organic compound frequently found as an indoor air contaminant. Formaldehyde occurs naturally outdoors without causing ill effects, but at elevated concentrations indoors it irritates the eyes, skin, and respiratory system. The exposure guideline recommended by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) is 0.10 parts per million (ppm). Most formaldehyde comes from manufactured goods used in the building, but tobacco smoke also contains formaldehyde. Significant sources in new structures include particle board, medium-density fiberboard, and plywood paneling. Other products such as furnishings, draperies, tapes, and some household chemicals also may be indoor sources of formaldehyde. Emission rates for formaldehyde have been shown to increase with increased indoor air temperature and relative humidity.

In addition to formaldehyde, numerous other VOCs can contaminate indoor air. More than 250 different chemicals have been measured at levels higher than 1 part per billion (ppb) in indoor environments. These chemicals include solvents used in paints, stains, adhesives, and caulking compounds. Chlorinated solvents are found in water repellents, cleaning fluids, and shoe polishes. The EPA is currently engaged in research efforts to characterize sources of indoor organic compounds and develop emission factors.[17] Table 3 lists typical indoor sources of VOCs.

Table 3

Typical Indoor Sources of VOCs

Compound(s)	Material Source(s)
Para-dichlorobenzene	Moth crystal, room deodorants
Methylene chloride	Paint removers
Chloroform	Chlorinated water
Formaldehyde	Pressed wood products, foam insulation, textiles, disinfectants
Styrene	Plastics, paints
Toluene diisocyanate	Polyurethane foam aerosols
Pthalic acid anhydride trimellitic acid, triethylene tetraamine	Epoxy resins
Sodium dodecyl sulfate	Carpet shampoo
Benzyl chloride, benzal chloride	Vinyl tiles plasticized with butyl benzyl phthalate
Ethylene oxide	Sterilizers (hospitals)

[17] B.A. Tichenor and M.A. Mason, "Organic Emissions from Consumer Products and Building Materials to the Indoor Environment," *Journal of the Air Pollution Control Association [JAPCA]*, Vol 38 (1988); Tichenor, B.A., et al., "Evaluating Sources of Indoor Air Pollution," *Journal of the Air and Waste Management Association*, Vol 40 (April 1990).

Table 4

Indoor Sources of Particulates*

<u>Building Materials</u>

Insulation
  Fiberglass fibers
  Cellulose fibers

Fire retardant
  Asbestos

<u>Building Contents</u>

Combustion Devices
  Unvented gas range emissions
  Unvented kerosene and gas heater emissions
  Wood stove and fireplace emissions

Occupants
  Bacteria
  Scales
  Viruses

Occupant Activities
  Tobacco smoke
  Aerosol sprays
  Cooking emissions
  Resuspended household dust

*Source: DOE/EV/10450-H1.

Particulates

The category of particulates includes a broad range of materials that may be found as solid particles or liquid droplets suspended in indoor air. Table 4 lists some of the more common sources of suspended particulates. Tobacco smoke is usually the largest source of breathable suspended particulates. Wood stoves and fireplaces can also be particulate sources when being started, refueled, or during accidental upsets. Unvented gas appliances and kerosene heaters may also produce suspended particulates. Building materials of various kinds may produce particulates as they age. Outdoor sources include windblown dust, pollen, and spores.

As an indication of the relative magnitudes of particulate sources, sidestream (uninhaled by the smoker) tobacco smoke produces approximately 40 mg of particulates per cigarette, compared to 4.6 mg per hour per burner for a gas stove, 0.1 mg per hour for a gas oven, and 0.2 to 3.2 mg per hour for gasfired unvented space heaters.[18] The typical indoor range for total suspended particulates of all sizes is 30 to 100 $\mu g/m^3$ averaged over 24 hours with maximum readings in the range of 600 $\mu g/m^3$.

Particle size and chemical composition determine the relative health impacts of suspended particulates and vary widely. Major health effects attributed to exposure to particulates include impairment of respiratory mechanisms, aggravation of existing respiratory and cardiovascular disease, and allergic reactions.

Radon Gas

Radon gas is a chemically inert, naturally occurring radioactive decay product of radium-226, which in turn, is a decay product of uranium-238. Radon belongs to the noble gas series, whose members also include helium, neon, argon, krypton, and xenon. Both uranium-238 and radium-226 are found in most soils and rocks, although their concentration, and that of radon gas, varies widely by region. Because radon is a gas, it can easily be transported through soil or dissolved in water. Radon gas can enter structures through any direct path between the structure and the soil, and through water from wells. When this gas is trapped within a structure, potentially harmful concentrations of radon can develop.

Radon undergoes radioactive decay with a half-life of 3.82 days, into a series of solid, short-lived radioisotopes collectively referred to as radon "daughters." The first four of these daughters—polonium-218, lead-214, bismuth-214, and polonium-214—are the most important sources of cancer risk from radon.[19] These solid materials become attached to suspended dust particles which, when inhaled, can stick to bronchial passages. In particular, polonium-214, and 218 emit alpha particles, a short-lived, but highly ionizing radiation that can damage cells, increasing the risk of lung cancer.

The radiation dose from inhaled radon daughters makes up about half the total dose from natural radiation received by the general public. Data suggest that in the United States, radon-222 concentration in residences averages about 1 picocurie/liter (pCi/l), but indoor levels are frequently encountered in the range of 10 to 100 pCi/l. Table 5 indicates the relative risks associated with exposure to radon, based on an individual spending 75 percent of his or her time indoors for 70 years. Currently, the recommended guideline for radon exposure has been set by the EPA at 4 pCi/l.

Concern about radon has centered on residences and low-rise structures. A recent study of radon in low-rise school buildings, potentially similar to typical administration/classroom buildings on Army installations, suggests that HVAC system operation can play an important role in determining indoor radon concentration.[20] The study found that under certain circumstances improper operation of the HVAC system could create a negative pressure within a structure, resulting in increased radon migration into the structure from the soil. The study also found that when ceiling return air plenums are intersected by block walls penetrating the floor slab, the negative pressure in the plenum can induce radon gas migration through the core of the block wall. Also, elevated levels of radon were found when air handlers were turned off at night. Overnight levels as high as 100 pCi/l were reached on first floor levels when air

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[18] DOE/EV/10450-H1.

[19] Rhonda S. Berger, "The Carcinogenicity of Radon," *Environmental Science and Technology*, Vol 24, No. 1 (1990).

[20] K.W. Leovic et al., "The Influences of HVAC Design and Operation on Radon Mitigation in Existing School Buildings," *IAQ89 The Human Equation: Health and Comfort* (ASHRAE, 1989).

Table 5

Radon Risk Evaluation Chart*

Exposure Level (pCi/l)	No. of excess lung cancer deaths (per 1000)	Comparable Risk
200	440 - 770	4 pack/day smoker
100	270 - 630	>60 x nonsmoker risk
40	120 - 360	20,000 chest x-rays/yr
20	60 - 100	2 pack/day smoker
10	30 - 120	5 x nonsmoker risk
4	13 - 50	200 chest x-rays/yr
2	7 - 30	
1	3 - 13	nonsmoker risk
0.2	1 - 3	20 chest x-rays/yr

*Source: *A Citizens' Guide to Radon*, EPA-86-004 (EPA and Centers for Disease Control: Washington, DC, August 1986).

handling fans were turned off at night during hot weather. Continuous operation of the fans reduced radon levels to 4 pCi/l.

Combustion Gases

In addition to cigarette smoke, there are a number of other combustion-related sources of gaseous and particulate indoor air contaminants. These sources include gas stoves and ovens, wood stoves, unvented gas heaters, kerosene heaters, and fireplaces. In particular, these indoor combustion sources have been associated with the production of polynuclear aromatic hydrocarbons (PAHs) and related compounds. Because many of these compounds are known to be carcinogenic, and because many more show potential carcinogenicity, exposure to them is of a major concern.[21] Other contaminants generated by combustion appliances include carbon monoxide, nitrogen oxides, sulfur dioxides, and particulates. Emission rates are influenced by the type of fuel and the combustion efficiency of the appliance which, in turn, is related to its design, operation, and maintenance. A study of 150 residences with kerosene heaters or gas stoves found nitrous oxide levels four to five times higher than in homes without kerosene heaters. Levels exceeding the EPA annual average ambient health standard of 100 $\mu g/m^3$ were found in 5 percent of the homes with either a gas stove or a kerosene heater. Sulfur dioxide levels exceeded the EPA standard of 80 $\mu g/m^3$ in 20 percent of the homes with kerosene heaters.

Data indicate that contaminants from indoor combustion sources can have health impacts. In a study of homes with wood stoves, young children from homes using wood-burning stoves for heating had a

[21] R.G. Lewis and L. Wallace, "Workshop: Instrumentation and Methods for Measurement of Indoor Air Quality and Related Factors," *Design and Protocol for Monitoring Indoor Air Quality*, ASTM STP 1002 (ASTM, 1989).

significantly greater incidence of bronchitis, upper respiratory infections, and pneumonia.[22] It was also found that the illnesses lasted longer for children whose homes were heated by wood stoves than for children whose homes were not. This study did not attempt to determine which components of wood smoke may have been the causal factor but indicated that many of the constituents acting together could potentially hamper the respiratory system defense mechanisms.

Data on effects of low-level exposure to nitrogen oxides from combustion sources are inconclusive, but there is evidence that levels of these gases indoors can reach levels known to be harmful to health.[23]

Pesticides

Many different kinds of pesticides are commonly used in residential and office environments. Misuse or improper storage and handling of pesticides can contribute to poor IAQ. Pesticides are a source of semivolatile organic compounds (SVOCs), which can have irritant or toxic effects on humans. Typical pesticide chemical families include organochlorine, organophosphate, organonitrogen, and pyrethroids, as well as polychlorinated biphenyl (PCB) mixtures.

Very little human exposure data is available to estimate potential health impacts due to nonoccupational exposure to pesticides. Air monitoring of homes in North Carolina by the EPA found six pesticides are commonly present: chlordane, ronnel, dichlorvos, malathion, diazinon, and dursban. Except for chlordane, all are organophosphates. While they are relatively safe compared to other compounds, they are quite toxic.[24]

Some pesticides used in homes have been found to cause cancer in animals. These include captane, lindane, and chlordane. General use of chlordane was banned in 1975 but its use is still allowed for termite extermination. There have been complaints of improper application of chlordane resulting in contamination of the indoor environment.[25]

The pesticide pentachlorophenol (PCP) is used to preserve wood, wood starches, dextrin, and glues. In one newer California office building PCP was used as a preservative on 60 percent of interior structural beams and columns. Health officials advised that PCP levels of 0.03 mg/m^3 might result in discomfort or health effects.[26] Remedial work, consisting of sealing exposed portions of the PCP-treated wood, resulted in levels dropping below 0.01 mg/m^3.

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[22] J.S. Osborne III and R.E. Honicky, "Health Effects of Heating with Wood: Chest Illness in Young Children and Indoor Heating with Wood Stoves," *IAQ89 The Human Equation: Health and Comfort* (ASHRAE, 1989).

[23] DOE/EV/10450-H1.

[24] DOE/EV/10450-H1.

[25] DOE/EV/10450-H1.

[26] H. Levin and T.J. Phillips, "Indoor Air Quality and Ventilation Measurements in Energy-Efficient California State Office Buildings," *Design and Protocol for Monitoring Indoor Air Quality*, ASTM STP 1002 (ASTM, 1989).

4 ARMY INSTALLATION IAQ MANAGEMENT PLAN

The purpose of an IAQ management plan is to integrate indoor air quality concerns and procedures into ongoing installation O&M activities. The principal objective of a plan is to prevent the occurrence of IAQ problems. Implementation of the plan will be undertaken by an IAQ coordinator (or coordinators) chosen from the installation Directorate of Engineering and Housing (DEH) staff. The specific form of an installation IAQ plan will vary from one installation to another, but all will include the following common elements:

1. Indoor air quality database
   a. Control of contaminant sources
   b. Tracking occupant complaints and symptoms
   c. Tracking problem resolution.

2. O&M activities
   a. Routine
   b. Special cases
      i. New buildings
      ii. Accidents and problems
   c. Management options for the control of tobacco smoke.

IAQ Database

The purpose of an IAQ database is to provide a central location for data elements necessary for managing the IAQ plan. Installations having access to computers and database software will find it helpful to implement the IAQ database as an automatic data processing (ADP) application. The database may stand alone or be integrated with an existing DEH database. The database can also be maintained in paper form.

Individual buildings are the key elements of the database. For each building, information is gathered regarding building characteristics and location, contaminant sources contained within the building, histories of IAQ problems, and present status of resolving any ongoing IAQ problems. Some specific subelements for each building within the database are listed below.

Building Age (or Date of Construction)

Knowing the building age allows some assessment of the building's potential state of repair, the design philosophy and ventilation standard employed in construction, the potential presence of asbestos, etc. This data element may also be useful in cross-referencing IAQ problems as they occur.

Building Type

This element provides a means of segregating potential IAQ problems. For example, radon may generally be a residential problem while VOCs may be more likely to be found in administration buildings. This data element may also be useful in cross-referencing to ventilation standards for particular building types and in categorizing the occurrence of IAQ problems by building type.

Building Design Reference (or Contract Number)

This data element indicates the generic design of the building and the contractor who performed the construction. This data can be useful in tracking material-related problems, design idiosyncracies or flaws, and as a general cross-reference for the occurrence of IAQ problems.

Building Physical Description and Use

This element consists of a number of subelements, including total floor area, approximate volume of occupied space, present and design usage, and current number of occupants. This data can be used in estimating a building's potential for having IAQ problems from insufficient ventilation or inappropriate use.

Building HVAC System Design/Operation

For each building the type of HVAC system should be described in detail. The type of air handling system should be noted, as well as the number and location of all air handlers. The location of all air intakes and exhaust vents should be listed. Reference should be provided to system control schedules where applicable, or the control schedule should be provided. If available, information on design ventilation rates should be provided, or the appropriate schedule or drawing should be referenced. This data element can be used in cross-referencing, and can also be provided as a printout to guide O&M personnel in inspection or troubleshooting.

Description of Building Location

The location of the building on the installation should be identified along with its geographic orientation. Prevailing wind direction information should also be provided. Nearest neighbor buildings should be identified as well as any significant air quality factors (e.g., mess hall located to the south, washrack adjacent on west, etc.).

Description of Contaminant Sources Within Building

Chapter 2 discusses various known causes of IAQ problems, and Chapter 3 discusses specific types of indoor air contaminants. This element of the database should be structured to contain information on each contaminant as a subelement. Information for these data elements should be gathered annually, either using an occupant questionnaire or by a building walkthrough.

Tracking Occupant Symptoms and Problem Resolution

Subelements of this database element include data on specific symptoms noted by building occupants complaining of unacceptable IAQ. An example survey for determining occupant complaints is included as Appendix A. Subelements may consist of specific symptoms, such as eye irritation, coughing, stuffiness, etc. Also included as subelements are the dates of complaints and progress made toward problem resolution. This element of the database should be carefully maintained and documented since legal actions can arise in cases of extreme IAQ problems. This key element, when cross-referenced with other building characteristic data elements, can help predict the potential for IAQ problems in other specific buildings.

Operations and Maintenance Activities

Existing HVAC O&M activities center around maintaining building occupant comfort in terms of temperature and humidity. O&M procedures for IAQ are not significantly different, but include a focus on aspects of existing procedures that impact the third factor in occupant comfort: indoor air quality. Case studies of O&M-related IAQ problems have not shown that new activities are needed, but that problems arise when well known, accepted procedures are not followed.

Many installations have preventive maintenance schedules either on paper or as computerized systems. As part of the IAQ management plan, the specific IAQ O&M activities indicated here will be integrated into the existing preventive maintenance scheduling, or, alternatively, managed as an element of the IAQ database previously discussed.

Chapter 5 of this report discusses O&M activities on a component level, from the perspective of indoor air quality impact. Within the IAQ plan these activities are implemented either on a routine basis, or in special cases such as the acceptance of a new building, installation of new furnishings in an existing building, or after storm or fire damage.

Routine O&M for IAQ

Routine O&M procedures for IAQ concentrate on proper operation and maintenance of building HVAC system components and control of indoor air contaminant sources. Specific components identified as having IAQ impacts are listed in Table 6 and are discussed in detail in Chapter 5.

An O&M checklist for the items listed in Table 6 is provided in Chapter 5 of this report. This checklist itemizes the minimum IAQ operations and maintenance activities required. Prioritization of buildings within an installation may be based on data gathered and stored in the IAQ database.

Table 6

IAQ Operations and Maintenance Items

Ventilation Rates	Humidifiers
Decentralized Coils	Decentralized Filters
Central Filters	Electronic Air Cleaners
Other Air Cleaners	Insulation
Economizer Systems	Cooling Towers
Evaporative Condensers	Air-to-Air Heat Exchangers
Pesticide Control	Sumps
Plumbing Systems	Lighting Systems
Refrigeration Equipment	Exhaust Hoods

Special Operations and Maintenance for IAQ

There may be several conditions under which special O&M procedures must be followed to ensure maintenance of acceptable IAQ. These include commissioning of new buildings, after extensive retrofit and refurnishing, after building structural damage due to storm, fire, or other cause, and as part of mitigating certain IAQ problems such as asbestos.

Commissioning of New Buildings and Installation of New Furnishings

The commissioning of new buildings and installation of new furnishings are singled out as special concerns in IAQ operations and maintenance because there have been several cases in which severe problems have occurred shortly after occupation of a new building or after installation of new furnishings. These problems have generally been related to large quantities of VOCs being released from new furnishings and building materials, and to initial failures in the operation of HVAC equipment. In one case an individual suffered irreversible brain damage due to the buildup of fumes from carpet glue after the installation of a new carpet.[27]

A building commissioning procedure developed by the State of California[28] is reproduced below with some technical and procedural modifications for Army installation use The object of this procedure is to accelerate outgassing of VOCs and other chemicals from building materials and furnishings through a "bakeout" procedure, and then to measure the levels of chemical contaminants remaining in the indoor air.

The use of bakeout procedures is not well documented at this time. Generally, these procedures call for raising the internal temperature of a building above normal levels for a period of time to accelerate outgassing of VOCs. However, this will only be effective if building ventilation rates are raised at the same time. If ventilation rates are not increased, the rate of outgassing will slow down as the concentration of chemical contaminants in the air approaches equilibrium with the concentration of contaminants in building materials and furnishings. Also, if ventilation rates are not increased during bakeout, contaminants may accumulate on interior surfaces and create new contaminant sources. The State of California procedure has been modified below to require 100 percent exchange of air during the bakeout procedure.

Building Commissioning Procedure For IAQ

1. The scheduling of commissioning testing should be coordinated with the contractor, the U.S. Army Corps of Engineers contracting officer, and the installation environmental engineering office. Coordination of testing shall be done by the Corps inspector assigned to the construction project. The procedures and equipment to be used will be reviewed by the installation environmental engineer and the Coprs project manager.

2. The criteria used for air quality sampling within the building will be determined by recognized air quality standards, such as those referenced in ASHRAE Standard 62-1989. *Ventilation for Acceptable Indoor Air Quality.*[29]

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[27] Lawrence S. Kirsch and Bonnie Y. Hochman, "As SBS Suits Increase, Owners and Tenants Suffer," *Indoor Air Pollution Report* (Leader Publications, NY, September 1990), p 6.

[28] H. Levin and T.J. Phillips.

[29] ASHRAE 1989.

3. When attempting a bakeout in new buildings to stimulate outgassing of various materials and furnishings, consideration must be given to HVAC design, including effects of internal heat loads of people, lights, and equipment. When performing the bakeout the building must be fully illuminated and other systems operating (where feasible) to raise the temperature to the maximum thermostat setting, if possible. The ventilation system should be operated to exchange 100 percent of the inside air for outside air during the bakeout procedure.

4. About 30 days should be allowed to provide adequate time for testing.

5. Chemical additives intended for routine use in HVAC equipment should be reviewed by the installation environmental engineer.

A typical building test procedure is as follows:

1. HVAC and electrical systems are inspected to determine that

   a. The HVAC system has been completed as per contract.
   b. The HVAC system has been balanced as per contract specifications.
   c. Other systems have been completed according to the contract.

2. The building interior shall be cleaned and free of standing water before testing.

3. Movable screens and furniture shall be installed before the test.

4. The HVAC system shall be set to operate in maximum heat mode and 100 percent outside air ventilation for 12 to 24 hours, with full illumination until a predetermined temperature is reached.

5. The HVAC system shall be set to operate in normal mode for 12 to 24 hours after a predetermined temperature is reached. Complete ventilation of inside air should be continued during this period.

6. The HVAC system shall again be set to operate in maximum heat mode and 100 percent outside air ventilation for 12 to 24 hours, with full illumination until a predetermined temperature is reached.

7. The HVAC system shall be set to operate in normal mode at normal ventilation rates for 12 to 24 hours following the second bakeout period.

8. Set up air sampling equipment.

9. Perform air sampling procedures.

Management Options for the Control of Tobacco Smoke

Management options for controlling the IAQ impacts of tobacco smoke in Army buildings will be determined by current policies on smoking in Government facilities and by the necessity of providing a comfortable and productive environment for all occupants . ne range of options available includes the following:

Restrict Smoking to Designated Areas. Under this option certain areas within a building are designated as smoking areas. This can be most effective if consideration is given to the relationship between the smoking area, the building HVAC system, and nonsmoking areas. A survey of the HVAC system may indicate that it is possible to segregate smokers and nonsmokers into areas served by different air handlers, and electronic air cleaning equipment can help ensure acceptable air quality. Other smoking room choices might include areas where window ventilation or exhaust fans are installed. Some data indicate that use of room air electrostatic precipitators or air ionizers can help mitigate effects of cigarette smoke.

Designate Smoking and Nonsmoking Buildings. It may be possible in some cases to segregate smoking and nonsmoking personnel into separate buildings. An advantage of this option is complete elimination of second-hand smoke effects on nonsmokers. Smokers' buildings could be retrofit for higher ventilation rates and use of electronic air cleaners.

Provide Counseling to Help Smokers Quit. Smokers should be offered counseling on methods of quitting smoking. This counseling could be provided by employee assistance programs acting in cooperation with local healthcare agencies.

Provide Counseling to Nonsmokers. This would include assessing on an individual basis the degree to which nonsmokers are experiencing discomfort due to cigarette smoke. An awareness of overall patterns of sensitivity could be used as an aid in determining office partners, work details, and other interactions among smokers and nonsmokers. Attention to the individuals with greatest sensitivity may eliminate the need for more drastic abatement measures.

5 PREVENTIVE OPERATIONS AND MAINTENANCE GUIDANCE

General IAQ Maintenance Checklist

Maintenance frequencies for HVAC equipment are described in Technical Manual (TM)5-671 and TM5-643. Table 7 is from TM5-671.

In addition to the schedules presented in the technical manuals mentioned above, other maintenance activities with IAQ impacts are listed below for spring and winter startup operations. Activities described below are the minimum required for maintaining acceptable IAQ.

Table 7

Maintenance Schedule from TM5-671

Air conditioning central systems (attended)	D
Cold storage plants	D
Ice manufacturing plants	D
Air conditioning central systems (unattended)	W
Air conditioning units (self-contained)	M
Ice cube machines	M
Morgue refrigerators	M
Beverage coolers	Q
Evaporative coolers	Q
Frozen food cabinets	Q
Mechanical ventilation	Q
Open type self-service cases	Q
Reach-in refrigerators	Q
Walk-in refrigerators	Q
Domestic refrigerators	A
Water coolers	A

D - daily W - weekly M - monthly Q - quarterly A - annually

Notes:

1. The frequencies apply when the equipment is in active use. Equipment subject to seasonal use should be programmed for startup service and then visited according to the prescribed frequency.
2. The purpose of the daily visit is to determine that the equipment is functioning properly. Preventive maintenance of the components should then be programmed for completion within each month.
3. Frequencies of inspection for equipment not shown will be determined locally.

Spring Startup Checklist

1. Inspect and maintain ventilation system air intakes, plenums, exhausts, ceiling plenums, VAV boxes, air supply diffusers, and air returns.

2. Perform filter and air cleaner maintenance.

3. Drain humidifiers and clean pans.

4. Perform refrigeration system maintenance.

5. Check cooling coil condensate drains and traps.

6. Perform fan-coil unit maintenance (decentralized coils).

7. Perform economizer cycle maintenance.

8. Perform cooling tower and evaporative condenser maintenance.

Winter Startup Checklist

1. Perform indoor air contaminant inventory; update IAQ database.

2. Inspect and maintain ventilation system air intakes, plenums, exhausts, ceiling plenums, VAV boxes, air supply diffusers, and air returns.

3. Perform filter and air cleaner maintenance.

4. Clean heating and cooling coils, inspect ducts for signs of moisture carryover.

5. Maintain air washers and humidifiers.

6. Perform heating system maintenance.

7. Maintain air-to-air heat exchangers.

8. Perform lighting system maintenance.

9. Perform exhaust hood maintenance.

Ventilation System Inspection

A key factor in maintaining acceptable IAQ is adequate ventilation using outdoor air of good quality. The following section provides a brief narrative description of inspection of a typical ventilation system. Figure 1 is provided as a general reference; actual air handler configurations will vary from one system to the next, and maintenance personnel should refer to the applicable mechanical drawings and specifications.

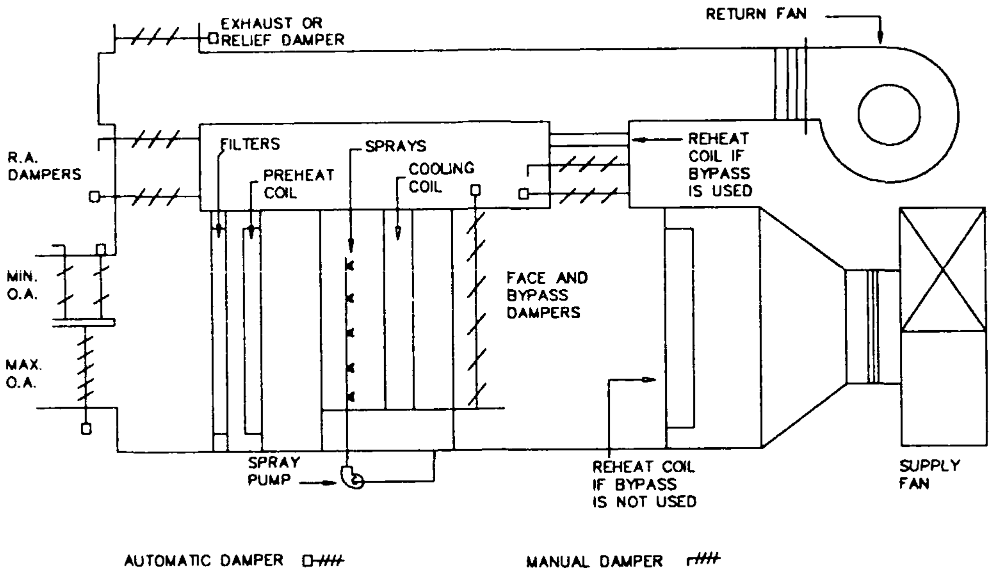

Figure 1. Equipment arrangement for central systems. (Reprinted by permission of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers from the 1987 *ASHRAE Handbook—Systems.*)

Operations and maintenance personnel should approach ventilation inspection by first becoming familiar with the location of air intakes and exhausts on each of the installation's buildings (or at least on each generic building type). Air intakes should be examined to determine if they are blocked in any fashion, if there are any pollution sources near the intakes, and if there is any evidence of possible short-circuiting of exhaust air into air intakes. Pollution sources to look for near air intakes include garbage dumpsters, vehicle parking or unloading areas, maintenance activities such as painting or cleaning, and vegetation with the potential to produce allergic reactions in building occupants.

Following examination of the general environment of the air intakes, a closer inspection should be performed to determine if intake screens and louvers are clean and intact, not blocked by leaves, vegetation, dirt, dead insects, etc. The presence of air intake flow should be ascertained using a rotating-vane anemometer, fiber tuft, or similar device. During occupancy hours under mild loads, particularly in the spring and fall, appreciable air flow should be readily discernible.

Each of a building's air handling systems should be inspected periodically. The first element to be examined should be the return and outside air mixing plenum. This space is located between the outside air intakes, return air supply duct, and the filter. Access may be gained by opening the access panel nearest the outside air intakes; in large systems this plenum area may be a small room. Upon gaining access to the plenum, the positions of the outside air and return air dampers should be examined to determine if they are set properly for the season. The minimum outside air damper should not be closed if the fan is operating. It may be partially closed in extremely cold or extremely hot weather. If a maximum outdoor air damper is also present, it may be closed in very hot or very cold weather, but should be open during mild weather when outside air can be used for free cooling. Figure 2 illustrates the relative amounts of outside air intake according to air temperature as measured for an office building.

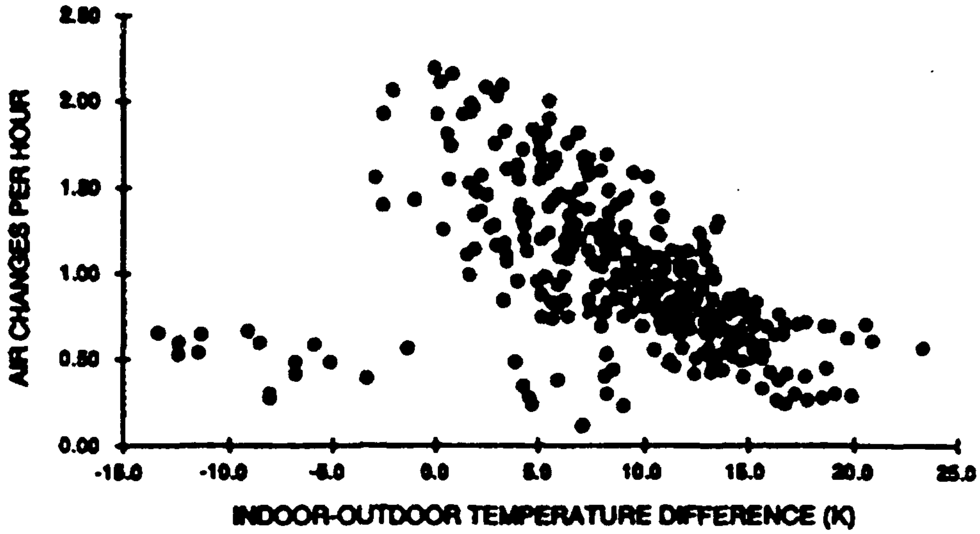

Figure 2. **Air exchange rate vs. indoor-outdoor temperature difference for an office building.** (Source: A. Persily, "Ventilation Rates in Office Buildings," *IAQ 89, The Human Equation: Health and Comfort.*)

After the damper positions have been inspected, plenum housekeeping should be examined. The plenum should be clear of dust and debris. If the plenum is a room, no paints, solvents, pesticides, paper, or wood products should be stored there. There should be no water on the plenum floor and the drain should be clear of debris.

Next, the filter bank should be inspected for missing filter elements. There should be no air pathways that allow air to bypass the filter bank. Filters should be maintained according to schedule.

Following inspection of the plenum area the access door should be closed, and the access door to the section containing the preheat coil, humidifier, and cooling coil should be opened. Coil surfaces should be checked for buildup of dirt and debris and growth of microorganisms. If the condensate drain pan is visible it should be checked for excessive dirt, odor, growth of microorganisms, and proper drainage. After inspecting this section the access door should be closed and the section between the cooling coils and bypass should be inspected. Again, if a drain pan is present it should be checked for dirt, debris, odor, microorganism growth, and proper drainage. Coil surfaces should be clean and free of dirt, debris, or biological growth.

Following inspection of the central air handler, the ventilation system supplying air to the conditioned space should be inspected. Ceiling plenums should be inspected for missing or damaged ductwork. The VAV volumetric flow control box(es) should be inspected to determine the damper minimum position setting. The minimum position is either set at the factory or in the field (after installation in the building). This minimum setting is determined by the design engineer and should be such that minimum total air supply to the space is sufficient to provide circulation and adequate outside air. In some cases, the minimum position may have been set at zero by mistake, malfunction, or neglect,[30] which will result in no airflow when the system is operating at minimum load conditions. It is important to verify the correct minimum setting and the proper operation of the damper.

Within the conditioned space, a survey should be conducted to determine the presence of contaminant sources such as those listed in Chapter 3. Data gathered should be recorded as input to the installation IAQ database. Indications of possible contamination include tobacco smoke, signs of mold or mildew, damp carpeting or furniture, chemical or other odors, presence of copying machines or other activities using volatile chemicals, excessive dust on flat surfaces or near air diffusers, and the presence of indoor combustion sources such as kerosene heaters. Certain contaminants such as asbestos and radon may not be easily detectable without instrumentation. Both of these contaminants may be addressed by the installation's environmental engineer.

Air supply and return registers should be examined to ensure that they are not blocked by equipment or furniture. Decentralized air handlers such as fan-coils should not be blocked by furniture or equipment, or have anything stacked on them. Missing or damaged ceiling tiles should be noted and replacement scheduled. The condition of the lighting system should be checked for inoperative or flickering lamps and dirty luminaires. Water leakage or other damage to windows should be noted and repair should be scheduled.

Ventilation Rates

Recommended mechanical ventilation rates for various building types are presented in Appendix B, taken from the ASHRAE Standard 62-1989, *Ventilation for Acceptable Indoor Air Quality*. The designs of many newer Army buildings have been based on older standards that allowed generally lower ventilation rates. It is possible, therefore, that any such newer buildings designed for energy conservation may not meet current ventilation standards.

For a given building, the total outdoor air intake is the sum of outdoor air provided by the mechanical ventilation system and by infiltration of outside air through leaks in the building envelope (or, in some cases, ventilation from open windows). The amount of air infiltration is related to many factors such as wind, air temperature differences between indoors and outdoors, building height, and building mechanical system. Recent studies have shown that air infiltration may be of the same order of magnitude as mechanical ventilation rates.[31] However, infiltration of outside air should not be relied upon for ventilation since it is unpredictable and because it is not conditioned or filtered.

Direct measurement of overall ventilation rates is difficult to determine and is probably beyond the scope of typical Army O&M activities. Present methods call for the use of tracer gas decay, and newer methods are being developed using measurements of indoor carbon dioxide. Recent data suggest that the average air exchange rate for office buildings with VAV air handling systems is about 0.9 air changes per

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[30] J. Woods, "Checking Out Building Ventilation," *Indoor Air Quality Update*, Vol 3, No. 6 (Cutter Information Corp., Arlington, MA., June 1990).

[31] A.K. Persily, and R.A. Grot, "The Airtightness of Office Building Envelopes," *Proceedings of the ASHRAE/DOE/BTECC Conference on the Thermal Performance of the Exterior Envelopes of Buildings III* (Clearwater Beach, FL, 1985); A.K. Persily and L.K. Norford, "Simultaneous Measurements of Infiltration and Intake in an Office Building," *ASHRAE Transactions*, Vol 93 (1987).

hour. In lieu of direct measurements, this data can be used as a rule of thumb in estimating cubic feet* per minute per person for office structures.

While measurement of overall air exchange rates is difficult, there are a number of instruments available for measuring air flow rates in ducts, at outside air intakes, and at room air diffusers. These devices include pitot tubes, hot-wire anemometers, rotating vane anemometers, and flow hoods. Army TM5-670, Section VII provides additional guidance on measurement of air flow in HVAC systems.

Maintenance of ventilation system components is critical to maintaining acceptable IAQ. Maintenance items include:

1. Fan motors, belts, and pulleys
2. Filters
3. Dampers, actuators, and controls
4. Plenums and ductwork
5. Diffusers.

Fan maintenance consists of checking the fan drive for pulley alignment, belt tension, and condition of the belt. Frayed or worn belts should be replaced. Dirt, oil, and grease should be wiped from pulley sheaves and belts. Fan motor bearings should be checked for rough running and defective bearings should be replaced. Bearings should be lubricated when required. Motor startup should be observed for proper speed pickup. Dirt and dust should be wiped from the motor housing.

Filters should be maintained as described later in this chapter.

Dampers, actuators, and linkages should be inspected, and lubricated and adjusted as necessary. Outside air flow rates should be measured using pitot tubes, rotating vane anemometers, or similar devices. Appropriate correction factors should be applied for each type of instrument. Measured flow rate should be compared with data from appropriate drawings or schedules. Controls and thermostats should be checked for proper functioning and cleaned, repaired, or replaced as necessary. Inspection and maintenance of control thermostats is discussed in Section III, Paragraph 17, of TM5-643.

Plenums and ductwork should be inspected and cleaned of biological growths, excessive dirt, and construction debris. Plenums should be free from standing water. Where a room is used as an intake plenum, no paints, solvents, pesticides, or wood or paper products should be stored in the room. Plenum drains should be clear of debris. If a drain pan is present it should be clear of debris and the drain trap should be filled with water. Ducts should be inspected for moisture and condensation. In particular, insulated ducts should be inspected for wet insulation and biological growth. If wet, insulation should be replaced and the source of moisture should be eliminated. Potential sources include insufficiently dehumidified air, malfunction of humidifier components, and carryover of condensate from cooling coils.

Room air diffusers should be checked for dust buildup and cleaned if excessive dust is noted. Air supply and return registers should not be blocked by furniture or equipment. If ceiling plenums are used as air supply or return plenums, missing or damaged ceiling tiles should be replaced. Ceiling plenums should be inspected for missing or damaged ductwork.

* 1 cu ft = 28.32 l.

The VAV volumetric flow control box(es) should be inspected to determine the damper minimum position setting. The minimum position is either set at the factory or in the field (after installation in the building). This minimum setting is determined by the design engineer and should be such that minimum total air supply to the space is sufficient to provide circulation and adequate outside air. In some cases, the minimum position has been set at zero by mistake, malfunction, or neglect.[33] This will result in no airflow when the system is operating at minimum load conditions. It is important to verify the correct minimum setting and the proper operation of the damper.

Humidifiers

Relative humidity levels between 60 percent and 20 percent are considered appropriate for human comfort. Relative humidity has also been shown to have a significant effect in the control of airborne infection. The 1983 ASHRAE Equipment Handbook indicates that at 50 percent relative humidity, mortality rates of certain organisms are highest, and influenza virus loses much of its virulence.[34] For these reasons, various systems are used to humidify air during heating seasons to avoid extremely low indoor humidities.

Several different types of humidifying equipment are discussed below.

Residential Humidifiers for Central Air Systems

Pan Type. These devices generally consist of a shallow pan located in the furnace plenum with a flow control device connected to the household water supply to maintain the water level. Evaporation may occur from the water surface, from wicked plates mounted in the pan to increase surface area, or from the surface with augmentation by electrical resistance heating.

Wetted Element Type. These devices use open-textured wetted media through or over which air is circulated. The evaporating surface may be a fixed pad, wetted by sprays or flowing water, or the pad may be a paddle wheel, drum, or belt rotating through a water reservoir. Air flow is driven by the furnace fan or a separate fan within the humidifier.

Atomizing or Cool-Mist Type. In this type of humidifier small droplets of water are created and introduced into the air. The droplets may be created by a spinning disc or cone, by spray using water pressure to create fine droplets, by a rotating disc that slings water droplets, or by rapidly vibrating membranes.

Residential humidifiers as stand-alone room units are available using most of the above humidification techniques.

Industrial Humidifiers for Central Air Systems

Heated Pan Type. This type of system consists of a pan of water located in the air handler or ductwork. The water is heated using steam, hot water, or an electrical element. Steam coils are

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[33] J. Woods.

[34] *ASHRAE 1983 Equipment Handbook* (ASHRAE, 1983).

commonly used with pan humidifiers. At steam pressures above 15 pounds per square inch (psi)* water carryover takes place due to nucleate boiling within the pan.

Steam Type. Direct steam-type humidifiers are available in a wide range of designs. The steam may be either supplied from an external source, as with enclosed grid, cup, or jacketed dry steam humidifiers, or produced within the humidifier, as in self-contained types. Steam humidifiers generally prevent free moisture from being introduced into the air; they can be used anywhere the air is dry enough to absorb the vapor.

Humidifiers can have a negative effect on IAQ in several ways, including contamination of pan-type humidifiers with biological growth, wetting of ductwork from carryover moisture resulting in biological growth, and release of boiler water treatment chemicals by steam humidifiers resulting in allergic reactions. ASHRAE Standard 62-1989 states that steam is the preferred humidification source if care is exercised with boiler water chemicals and steam additives.

Maintenance of humidifiers varies with type. Pan-type humidifiers should be drained and cleaned regularly, and at the end of the heating season. Make-up water valves should be cleaned of scale or other deposits. Condensate drain lines on steam humidifiers should be inspected for proper operation and cleaned as necessary.

Decentralized Coils and Filters

Decentralized coils and filters are used in air-and-water, and in all-water distribution systems. In air-and-water systems the most common type of terminal used is the high-pressure induction unit. Air supplied to the induction unit from the central mechanical room is called "primary air." Water distributed to the induction unit using two- or four-pipe systems, is termed "secondary water." Primary air provides outside air for ventilation; in the cooling season the air must be sufficiently dehumidified by the central conditioner to achieve comfort humidity conditions and to avoid condensation on the secondary water coil.

The general layout of an induction unit is shown in Figure 3. High-pressure air flows through induction nozzles and induces secondary room air over the secondary coil. This secondary air is heated or cooled as required. Normally, no latent cooling is accomplished by the room coil, and no condensate is expected. A drain pan for condensate is provided in case unusual short-term latent loads occur. There is typically no condensate removal piping. Excessive production of condensate in these systems can lead to IAQ problems.

Individual induction units do not contain fans, motors, or compressors. Routine maintenance is generally limited to temperature controls, cleaning the lint screen or filter, and occasional cleaning of induction nozzles. The primary IAQ-related O&M concerns for induction units are that:

1. Primary air flow may not contain sufficient outside air.

2. Secondary air flow can cause infrequently maintained coils and lint screens to become excessively dirty.

* 1 psi = 703.1 kg/m^2.

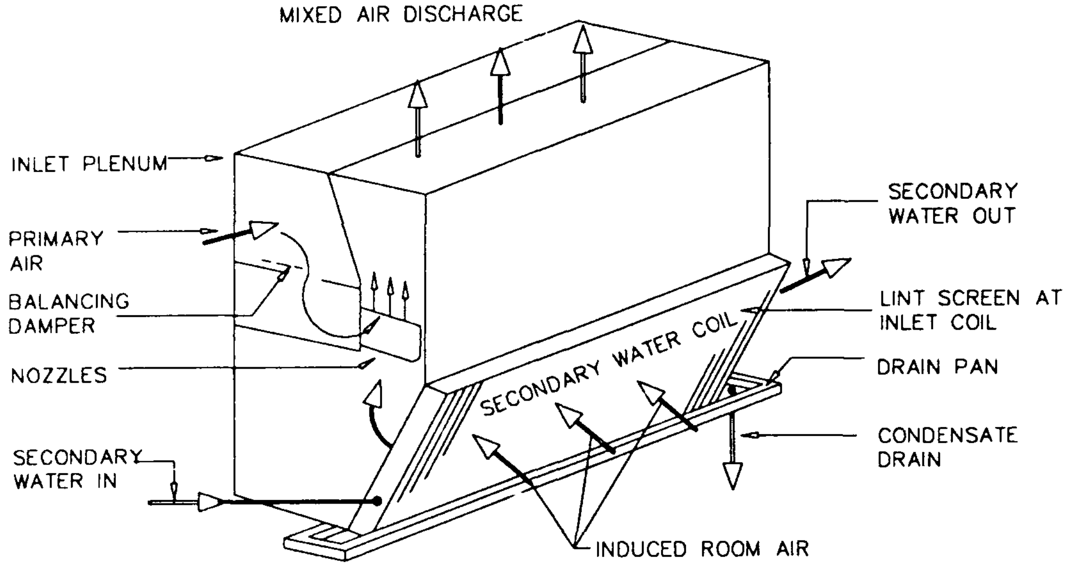

Figure 3. Air-water induction unit. (Reprinted by permission of ASHRAE from the 1987 *ASHRAE Handbook—Systems.*)

3. Insufficient dehumidification of primary air, or frequent excessive latent loads, can cause frequent wetting of the coil, standing water in the condensate pan, and microbial growth on wet, dirty coils and lint screens.

O&M of induction units for ensuring good IAQ requires that coils and lint screens are clean and that primary air is sufficiently dehumidified. Coils and lint screens may be cleaned by brushing, vacuuming, or wiping with a damp cloth. Sufficient dehumidification of primary air can be ensured by proper sizing of the central chiller and maintenance of the primary air cooling coil.

Fan-coil units, unit ventilators, and valance units are the most common terminals in all-water systems. Ventilation may be provided through open windows or a wall aperture, in which case the ventilating air load is handled by the terminal unit. Ventilation may also be provided by an interior zone system or a separate ventilation air system.

Figure 4 illustrates the basic features of a fan-coil unit. The primary elements of the fan-coil unit are a finned-tube coil and a fan section. The fan continuously recirculates air within the space over the coil where it is either heated or cooled. The unit may also contain an electric resistance, steam, or hot water coil. Because the cooling coil handles both latent and sensible loads, a condensate pan and drain system must be provided for each unit.

The IAQ-related O&M activities for fan-coil units are:

1. Cleaning or replacing the filter
2. Cleaning and flushing the condensate pan and drain system
3. Cleaning the coil
4. Ensuring that wall aperture air intakes are clean and free from dust, debris, corrosion, and insects.

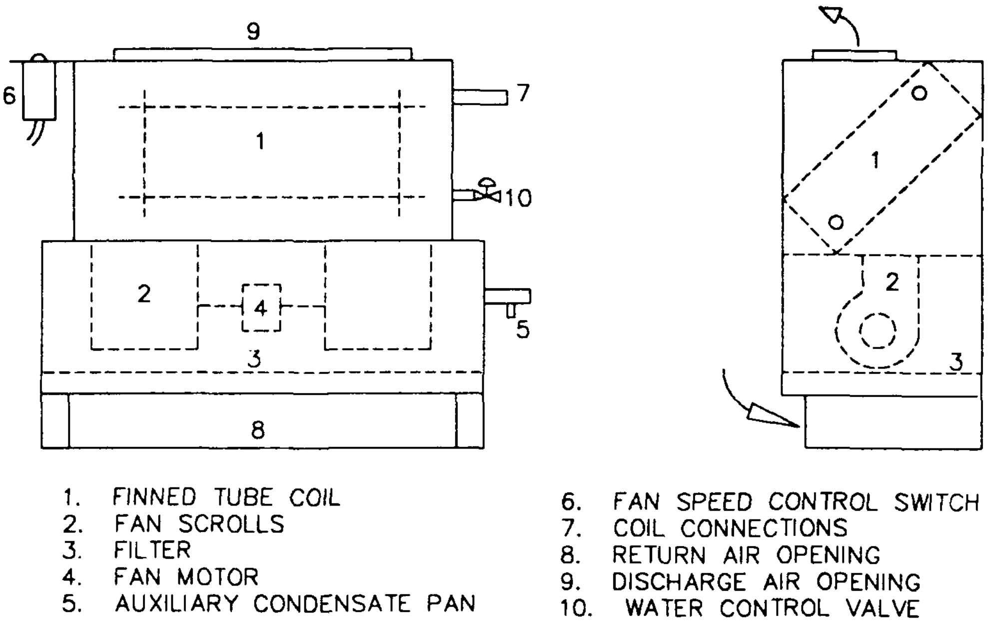

Figure 4. Typical fan-coil unit. (Reprinted by permission of ASHRAE from the 1987 *ASHRAE Handbook—Systems.*)

IAQ problems can occur if filters and coils become excessively dirty or if standing water accumulates due to problems with the condensate drain system. Operators sometimes seal outside wall apertures to conserve energy, leading to insufficient ventilation.

Filters

Filters are used in HVAC systems to remove dust from ventilation and recirculated air. The components of atmospheric dust can vary greatly, but typically they may include soot, smoke, silica, clay, decayed animal and vegetable matter, and microorganisms and products of organisms, such as mold spores and plant pollen. Any of these constituents of dust may produce negative impacts on IAQ, so effective air filtering is essential to maintenance of acceptable IAQ.

Air filters may be broadly classified as either fibrous media unit filters, or renewable media filters. Fibrous media unit filters are used until the accumulated dust load reduces air flow to an unacceptable level. When this happens these filters are replaced or reconditioned, depending on the type. Fibrous media filters include both viscous impingement and dry-type air filters.

Viscous impingement filters are flat panel filters made of coarse, highly porous fibers. The filter medium is coated with a viscous substance, such as oil, which acts as an adhesive on particles that impinge on the fibers. These filters are characterized by low pressure drop, low cost, good efficiency on lint, but low efficiency on normal atmospheric dust.

The manner of servicing fibrous media unit filters varies with construction. Manometer and draft gages are often installed to measure pressure drop across the filter bank to indicate when filters need servicing. Disposable filters are made of inexpensive materials and are designed to be discarded after use. Permanent filters are designed to be reconditioned through cleaning and reapplication of the adhesive material. Army TM5-670 and TM5-745 provide filter maintenance guidance.

Dry-type extended surface filters are made of random fiber mats or blankets of different thicknesses, fiber sizes, and densities. The filter medium is generally supported by a wire frame forming pockets of V-shaped pleats. In other designs the filter medium may be self-supporting because of inherent rigidity or because air flow holds it in place. In some designs the filter medium is replaceable and is held in position by permanent metal cells. In other designs the entire cell is disposed of after it has accumulated a full dust load.

Renewable Media Filters

Renewable media filters are designed so that fresh media are introduced into the air stream as needed, maintaining nearly constant pressure drop and efficiency. A typical renewable media filter is the moving-curtain viscous impingement filter. In this type of filter, a random-fiber medium is furnished in roll form. Fresh medium is fed across the surface of the filter automatically while spent medium is rewound on a second roll. When the filter medium is exhausted the take-up roll is discarded and a new roll is installed.

Maintenance of filters is an important part of providing acceptable IAQ. Army technical manuals TM5-670 and TN5-745 provide guidance on proper filter maintenance. Frequency of inspection and maintenance will depend on the type of filter and where it is installed. TM5-670 recommends that filters be cleaned or renewed at least every 3 months.

Electronic Air Cleaners

Electronic air cleaners use electrostatic principles to collect particulates but operate at lower voltages than commonly used industrial electrostatic precipitators. The designation "electronic air cleaner" is used to distinguish the class of electrostatic precipitator suitable for cleaning ventilation air in HVAC systems. There are three basic types of electronic air cleaners: ionizing plate type, charged media nonionizing type, and charged-media ionizing type.

Ionizing Plate Type

In this type of electronic air cleaner, positive ions generated at a high-potential ionizer wire flow across the air stream striking and adhering to any dust particles carried by the air stream. These particles then pass through a section of charged and grounded plates, where they are drawn to the plates by the electric field. Where lint is present in appreciable quantities, such as in recirculated air, a lint removal filter should be installed ahead of the electronic air cleaner.

Electronic air cleaners of the ionizing type are efficient, low-pressure-drop devices for removing fine dust and smoke particles. Collector plates are often coated with a special oil as an adhesive. Cleaning is generally accomplished by washing the plates in place with hot water from a hose or nozzle system. The bottom of the equipment is provided with a drain. Typically, safety interlocks are provided so high voltage equipment is inoperative if any access doors are opened. Maintenance personnel should make sure power is off before attempting to service electronic air cleaning equipment.

In some electronic air cleaners, no adhesive is applied to the collector plates. Under these circumstances, agglomerates may eventually be blown from the plates. With this type of equipment, a secondary filter is provided downstream to catch the agglomerates. This secondary filter is maintained by cleaning or replacement. TM5-670, Section X, and TM5-745, Section 7, provide additional details on maintenance of electronic air cleaners.

Charged Media Nonionizing Type

A charged media air cleaner combines certain characteristics of both dry filter and electronic air cleaners. The filter medium is usually arranged in pleats, but no ionization is employed. The filter medium consists of a dielectric material such as glass fiber mat, cellulose mat, or similar material in contact with a grid of alternately charged and grounded wires. An intense nonuniform electrostatic field is developed in the filter media. As particles approach the field they become polarized and are captured on the fibers of the filter medium. Unlike the ionizing plate type air cleaner, this type of cleaner offers resistance to air flow, and the filter medium must periodically be replaced.

Charged Media Ionizing Type

This type of electronic air cleaner combines a corona discharge ionizer with a charged filter mat. This arrangement provides higher efficiency than charged media without an ionizer. At least one study has shown this type of filter to be the most effective in removing environmental tobacco smoke.[35] Maintenance items include cleaning the corona discharge wire and replacing the filter medium.

Signs of Trouble

Problems with electronic air cleaners may include space charge and ozone.

Dust that passes uncaptured through an ionizer carries an electrical charge into the conditioned space. If this continues on a large scale, a space charge can develop that tends to drive charged dust to the walls. Under these conditions a relatively rapid buildup of dust may be noted on the walls, indicating the electronic air cleaner needs maintenance.

Certain malfunctions may cause an electronic air cleaner to produce ozone. Continuous arcing and brush discharge may yield annoying or even mildly toxic ozone levels, which will be indicated by a strong ozone odor. If an ozone odor is noticed the electronic air cleaner should be inspected. When operating properly, electronic air cleaners produce indoor ozone levels of only about 30 percent of outdoor levels.

Air Washers

Air washers are devices employed for humidification or dehumidification that also perform an air cleaning role. Two common types of air washers are the spray type and the cell type.

In spray type washers an array of nozzles is arranged so incoming air mixes with and penetrates the spray. The spray water is collected and recirculated. An eliminator section located at the exit of the washer removes entrained water droplets from the air stream. This type of washer is typically used as an evaporative cooler or humidifier and has relatively low air cleaning efficiency.

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[35] R.A. Jaisinghani et al., "The Effectiveness of Air Cleaners Using an Environmental Tobacco Smoke Material Balance Model," *IAQ89 The Human Equation: Health and Comfort* (ASHRAE, 1989).

In cell-type washers, water is passed over a matrix of cells packed with glass, metal, or fiber screens. Air flows over the surface of these cells. Following the cells are a section of eliminators to prevent water droplet carryover.

The particle removal efficiency of air washers depends on particle characteristics such as size, density, wettability, and solubility. In spray washers particle removal is largely the result of wet particle impingement on the eliminator plates and is not highly effective. In cell-type washers particles are removed from the air stream by impingement on the cell-water surface film. The air cleaning results are comparable to other impingement type filters.

Poor maintenance of air washers can result in IAQ impacts through poor filtering performance and by providing a growth environment for algae and bacterial slimes. Periodic inspection should be made to ensure that water lines, distribution troughs, pumps, and pump filters are clean and free of dirt, scale, and debris. Inspection should include checks for algae, slime, and bacterial growth. An EPA-registered biocide should be added if necessary.

In spray washers the spray nozzles should be frequently checked for clogging. Air washer tanks should be drained and dirt deposits removed on a regular basis. Moisture eliminators should be inspected for corrosion and other damage, and repaired and repainted as necessary. In cell-type washers the cell medium must also be cleaned and the mat-type mist eliminators should be removed and cleaned with detergent solution. TM5-670, Section XI, provides maintenance details for evaporative coolers. They also apply to air washers.

Insulation

Maintenance of insulation systems can aid in maintaining acceptable IAQ. Both internal duct insulation and condensate pan and drain line insulation should be inspected at regular intervals. Duct insulation should be carefully examined for signs of wetting from carryover moisture and signs of biological growth. Wet or damaged duct insulation should be replaced.

Condensate drain system insulation and other cold-water piping insulation is necessary to prevent condensation from forming on the exterior of cold pipes. If condensation occurs it may wet other materials, which become a source for biological growth. Missing or damaged piping insulation should be replaced.

Building envelope insulation may not be an ongoing maintenance item, but when retrofit insulation is added, care should be exercised if urea-formaldehyde foam is selected. In 1982 the Consumer Product Safety Commission imposed a nationwide ban on urea-formaldehyde foam, but this was later overturned by a court ruling. When improperly compounded or installed, urea-formaldehyde foam can emit significant levels of formaldehyde. Other types of foam insulation may also result in transient outgassing. Adequate excess ventilation should be provided for a period following installation of retrofit insulation.

Economizers

Economizer ventilation cycles are used to provide free cooling when outdoor air temperatures are low enough. Figures 5 and 6 show two typical arrangements of economizer cycles.

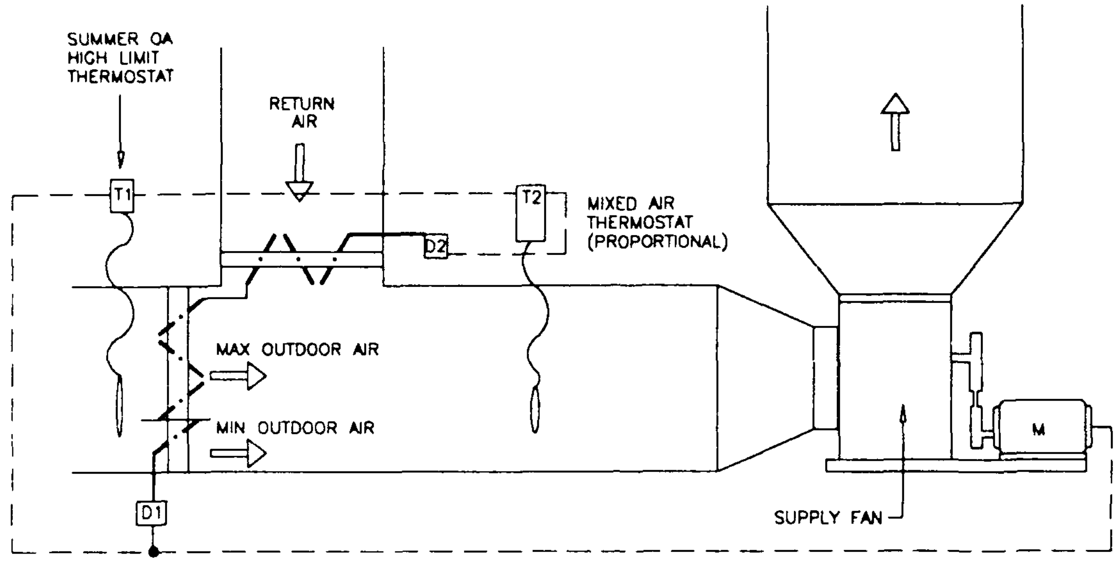

Figure 5. All-season ventilation control with fixed minimum outdoor air plus additional outdoor air when feasible. (Reprinted by permission of ASHRAE from the 1987 *ASHRAE Handbook—Systems.*)

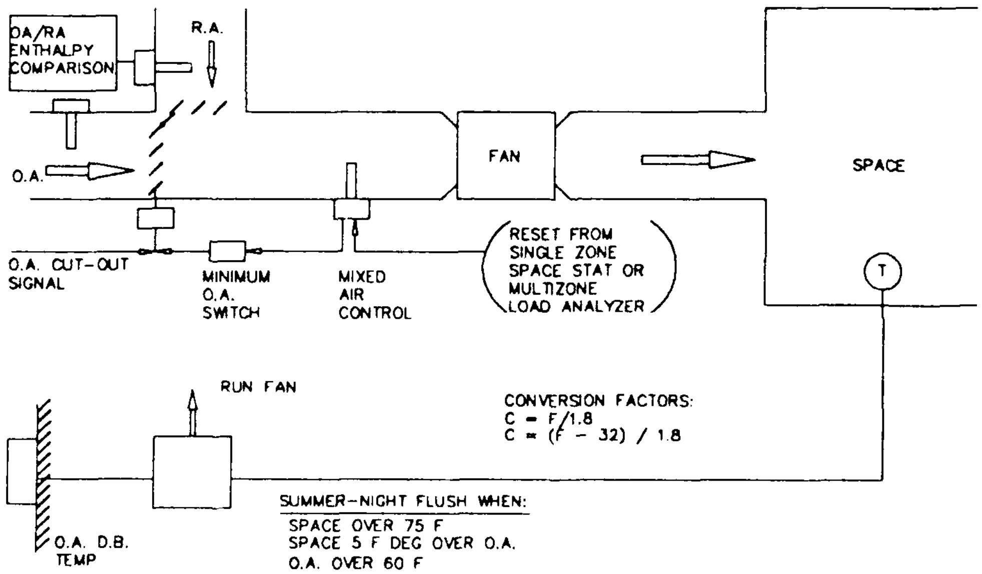

Figure 6. Economizer system with enthalpy changeover. (Reprinted by permission of ASHRAE from the 1987 *ASHRAE Handbook—Systems.*)

Figure 5 shows an all-season system with a fixed minimum outside air damper that opens whenever the fan is running, a maximum outdoor air damper that is automatically controlled by a mixed-air thermostat, and a high-limit outdoor air thermostat that returns the system to a minimum outside air condition. Whenever the outdoor air is warmer than the setting of the mixed-air thermostat and cooler than the setting of the high limit, 100 percent outdoor air will be used for ventilation.

For improved economy, the high-limit thermostat may be a wet-bulb or enthalpy-type device to provide a better indication of total heat in outdoor air. This system, shown in Figure 6, includes a mixed-air reset from zone demand for maximum energy conservation.

Maintenance of economizer cycles requires that dampers and linkages are properly maintained and that controls function as intended. Manual initiation of the economizer cycle, by changing thermostat settings, can be used to increase ventilation rates when necessary for special conditions such as installation of insulation or new furnishings.

Cooling Towers

Air conditioning and refrigeration systems operate by removing heat from air. One of the most common ways to accomplish this is with a cooling tower. In a cooling tower, water to be cooled is distributed in the tower using spray nozzles, splash bars, or filming-type fill, in a manner that exposes a large surface area to atmospheric air. The air is circulated through the tower using either fans, convection, or induced flow effects from the water sprays. Cooling of the water is accomplished through evaporation of a portion of the water by the circulating air. The cooled water is then supplied to the air conditioning or refrigeration system condenser, where it absorbs heat from the condensing refrigerant. Water lost through evaporation and drift of water droplets from the tower is resupplied by makeup water. The typical components of several types of mechanical draft (fan driven) cooling towers are shown in Figure 7.

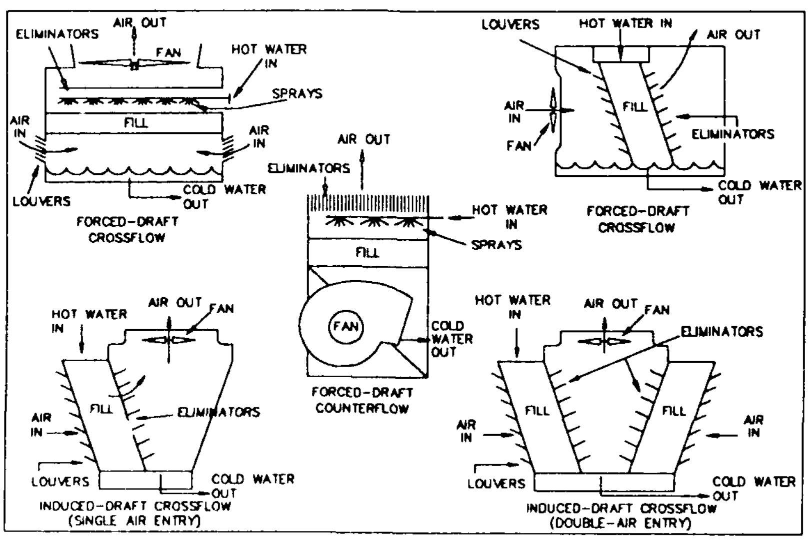

Figure 7. Conventional mechanical draft cooling towers. (Reprinted by permission of ASHRAE from the 1988 *ASHRAE Handbook—Equipment.*)

The quality of water circulating through the cooling tower can have a significant effect on overall system performance and, under certain conditions can have IAQ impacts. Since the water in these systems is cooled primarily by evaporation, concentrations of dissolved solids and airborne impurities such as dust and gases can increase rapidly. During normal operation, large quantities of airborne dirt can be introduced into the system, which can lead to growth of algae, slime, fungi, and other microorganisms (including legionella). These problems can be controlled through blow-down and chemical treatment to control scale, inhibit corrosion, and restrict biological growth. Typical scale inhibitors include acids and inorganic phosphates. Corrosion control may be achieved by introducing phosphates or polyphosphonates with zinc—either singly or in combination. Control of biological growths is accomplished by use of chlorine compounds such as sodium hypochlorate, or chlorinated phenols such as sodium pentachlorophenate.

The primary way cooling tower operations can impact IAQ is through drift. As water and air contact within the cooling tower, droplets are produced and entrained by the air stream. While most of these droplets are captured by the tower drift eliminators, some are discharged from the tower. Since these droplets contain dissolved minerals, water treatment chemicals, and biological materials, IAQ impacts can occur if drift enters outside air intakes and contaminates air handlers, or is otherwise brought into contact with building occupants. Cooling tower O&M activities associated with maintaining IAQ include:

1. Proper location of cooling towers relative to outside air intakes to avoid inflow of drift

2. Proper maintenance of cooling tower drift eliminators by replacing damaged or missing sections

3. Proper tower water treatment to control scaling, corrosion, and biological activity.

Sections XII through XV of TM5-670 provide specific details on cooling tower maintenance.

Evaporative Condensers

Evaporative condensers are similar in design to cooling towers. In an evaporative condenser, tube coils containing condensing refrigerant are directly cooled through contact with water sprays. These sprays wet the tubes while air simultaneously circulates over the coils. As the water evaporates in the air stream the tubes are cooled. Figure 8 illustrates the operation of an evaporative condenser.

IAQ impacts and ways to control them are the same as previously discussed for cooling towers.

Swimming Pools and High Humidity Spaces

Indoor pools and other high humidity spaces are generally designed to use up to 100 percent outdoor air for cooling and dehumidification. During the summer months, when outdoor temperatures and humidities may exceed design conditions, minimum outdoor air flow may occur.

Because of the high relative humidity, air quality impacts may occur due to wet or damp building materials, standing water in ducts, or wet duct insulation.

Heating and cooling coils, condensate drains, and filters should be maintained as described in pertinent sections of this chapter. Ductwork should be inspected for corrosion, standing water, or wet insulation. General operation and maintenance of swimming pool facilities is discussed in TM5-662.

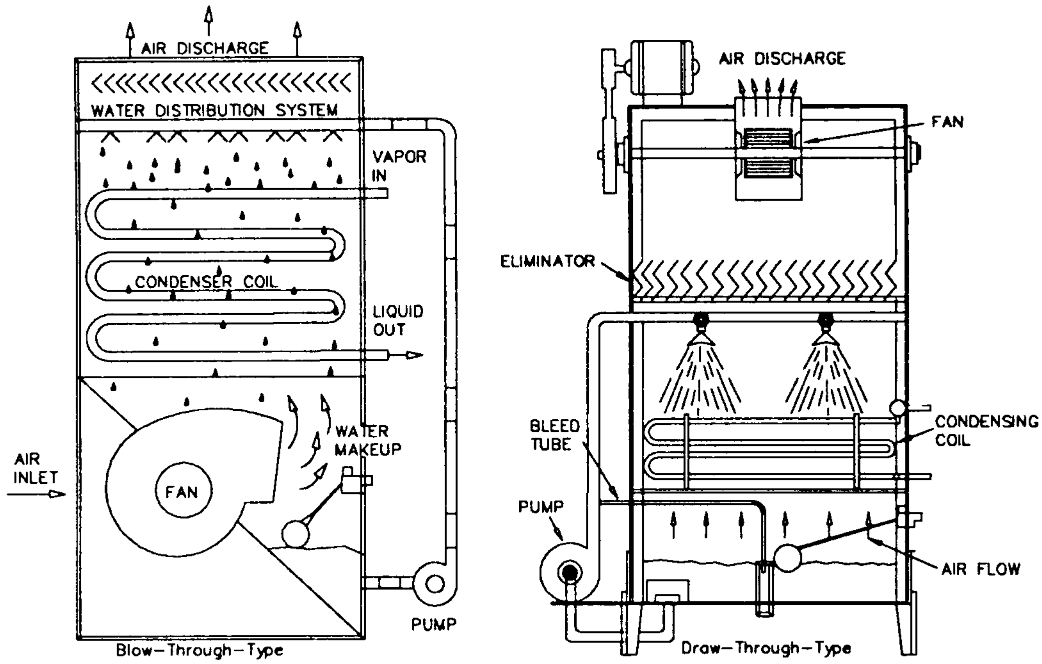

Figure 8. Functional view of evaporative condenser. (Reprinted by permission of the ASHRAE from the 1988 ASHRAE *Handbook—Equipment.*)

Air-to-Air Heat Exchangers

Air-to-air heat exchangers allow the exchange of heat, in some cases both sensible and latent, between exhaust and intake air streams. The use of air-to-air heat exchangers can promote energy-efficient building operation while allowing adequate ventilation for acceptable IAQ. There are several types of air-to-air heat exchangers, including rotary, coil energy recovery loops, heat pipe heat exchangers, and fixed plate heat exchangers.

Rotary Heat Exchangers

The rotary heat exchanger, sometimes called a heat wheel, is a revolving cylinder of an air-permeable medium that rotates through adjacent supply and exhaust air streams. The medium may be selected to transfer sensible heat, or both sensible and latent heat.

Rotary heat exchangers require a minimum of maintenance. Cleaning of the medium is required when lint, dust, or other foreign materials build up. Cleaning methods suitable for one type of medium are not necessarily suitable for other types. Media treated with a liquid desiccant for total heat recovery may not be wetted, but are cleaned by vacuuming the wheel face or using dry compressed air to blow out the passages. Metallic (and some nonmetallic) media may be vacuumed, blown out with compressed air, or cleaned with steam, hot water (with or without detergent), or a suitable solvent. The manufacturers' cleaning instructions should be followed. Drive motor and train should be maintained according to the manufacturer's instructions. Particular attention must be given to speed control motors that have commutators and brushes, because these require more frequent inspection and maintenance than do induction motors. Brushes should be replaced, and the commutator should periodically be turned and undercut. Wheels should be inspected regularly for proper belt or chain tension. The manufacturer's recommendations should be followed for spare and replacement parts.

Coil Heat Recovery Loops

A coil heat recovery loop consists of extended-surface finned-tube water coils located in the supply and exhaust air streams, connected by a closed loop with a pump. The system is generally used for sensible heat recovery.

Coil energy recovery loops normally operate with a minimum of required maintenance. The only moving parts are the circulation pump and three-way control valve. Maintenance includes cleaning or replacing of air filters, cleaning of the coil surface, and periodic maintenance of the pump and valve.

Coils can be cleaned with steam, compressed air, hot soapy water, or suitable solvents. If the exhaust air dictates frequent cleaning, automatic wash systems may be installed.

An inhibited ethylene glycol solution is normally used in the piping circuit to prevent freezing. The inhibitor should be maintained. Ethylene glycol solution should not be used in applications where the temperature exceeds 275 °F (135 °C).

Twin Tower Enthalpy Recovery Loop

This system consists of an air-to-liquid, liquid-to-air, direct-contact heat exchange system. Contactor towers are located in supply and exhaust air streams and a sorbent liquid is circulated between the towers, transferring both sensible and latent heat between the two air streams.

Twin tower enthalpy recovery systems are designed to operate with only routine maintenance. Periodically, as in comparable air washer systems, the circulation pumps, spray nozzles, liquid transfer controls, and mist eliminators should be checked, adjusted, and maintained as necessary. Inhibited halide brine solutions are normally used as the energy transfer medium. A bimonthly solution-sampling service is provided by manufacturers to monitor solution conditions and report to the operator changes necessary to ensure continued satisfactory performance.

Heat Pipe Heat Exchangers

A heat pipe heat exchanger uses a series of parallel heat pipes to transfer energy from the exhaust air stream to the intake air stream. The heat pipes span the width of the unit but a sealed partition separates the two air streams to prevent cross contamination.

Maintenance of heat pipe heat exchangers consists primarily of occasional cleaning. How the exchanger is cleaned depends on the nature of the material to be removed. Grease buildup from kitchen exhaust is often removed by automatic water wash systems. Other kinds of debris or residue must be sprayed clean with water or soaked in a cleaning solution.

Fixed Plate Heat Exchangers

Fixed plate heat exchangers may be classified as either pure plate heat exchangers, having only primary heat transfer surface, or plate fin heat exchangers, made of segmented plates and interconnecting fins. Plate heat exchangers are basically just counter, cross, or parallel flow heat exchangers. Figure 9 illustrates a residential fixed plate heat exchanger. Typically only sensible heat is transferred unless the temperature of one air stream is low enough to cause condensation in the other air stream. Plate type heat exchangers require little maintenance beyond periodic cleaning. They can be cleaned with compressed air, hot water, or steam. Automatic wash systems for cleaning remote units are available.

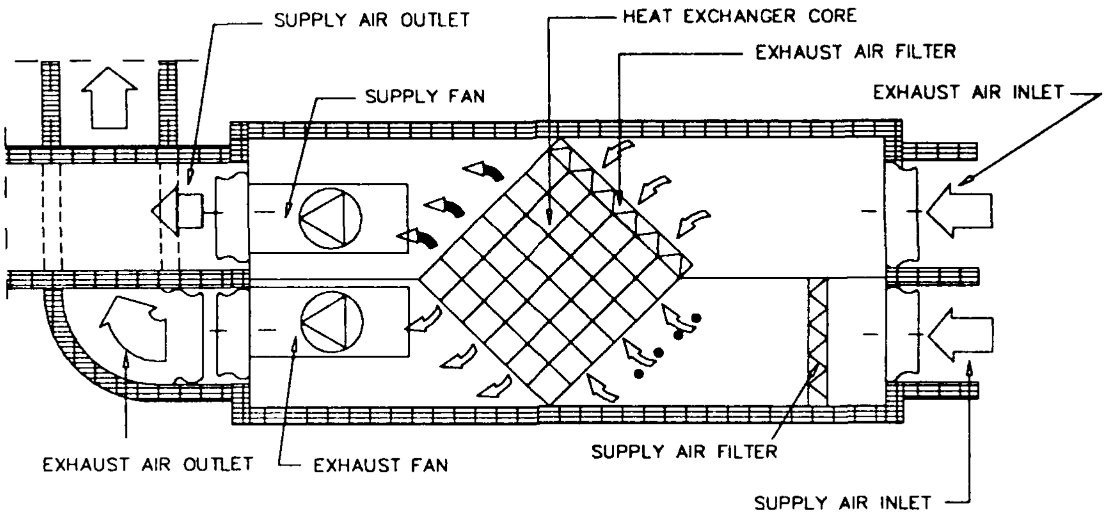

Figure 9. Schematic diagram of air-to-air heat exchanger. (Source: W.J. Fisk et al., *Indoor Air Quality Control Techniques, A Critical Review*, LBL-16493 [University of California Lawrence Berkeley Laboratory, March 1984], p 43.)

System Cleaning

Coils

Heating and cooling coils may require occasional cleaning to remove dust, lint, dirt, and other debris. In general, if proper filter maintenance procedures are followed, external coil surfaces should remain relatively clean. Coils occasionally wet by cooling coil carryover moisture may show greater buildup of contaminants, particularly if filters are poorly maintained. Dry coils may be brushed and cleaned with a vacuum cleaner. Both wet and dry coils may be cleaned with compressed air, hot water (with or without detergent), or steam. Condensate drain pans should be cleaned with diluted detergent at the same time as the coils, then thoroughly rinsed. In cases of extreme neglect it is sometimes necessary to remove the coils for more extensive cleaning with steam or compressed air.

Ducts

Sections of ducts that are easily accessible (e.g., plenums) can be cleaned by wiping with a damp cloth, brushing, or vacuuming. Room-size plenums can be swept or vacuumed. Relatively inaccessible duct sections may be cleaned by commercial cleaning contractors equipped with specialized vacuum systems.

Pesticide Control

Industrial pesticides should be applied using manufacturer's recommended procedures and safety precautions. Pesticides should not be stored in HVAC plenum areas or applied near outside air intakes while fans are running. If large-scale application of a pesticide is planned, building occupants should be informed about the type of pesticide to be applied, where it will be applied, and the time of application. When feasible, excess ventilation should be provided for a period following pesticide application. Information on proper pesticide handling and storage should be provided to base personnel living in family housing. Pesticide disposal should be coordinated with the base environmental engineering office.

Sumps

Sumps in family housing and other installation buildings may be a source of radon gas infiltration. Many installations have initiated radon testing programs. If elevated levels of radon are detected, one possible remedy is installation of a sump ventilation system. Figure 10 illustrates a typical installation.

Plumbing Systems

IAQ impacts related to plumbing system operation and maintenance deficiencies are usually related to problems with cooling coil and/or humidifier condensate drip pans, drains, or drain traps. Problems can occur if drip pans fail to drain properly due to improper installation, or if dirt and debris accumulate enough to clog the drains. If this occurs, standing water in the drain pan and ducts can host biological growths. Another problem is drain pan traps that have been allowed to dry out permitting sewer gases to enter the HVAC system. Condensate lines should be pitched to allow proper drainage. They should be of ample size—1.25 in. (3.175 cm)—and have a trap deep enough to resist 2 in. (5.08 cm) of water pressure differential. Connection between the drip pan and drain piping should be flush; no pipe lip should be present to allow standing water to collect.

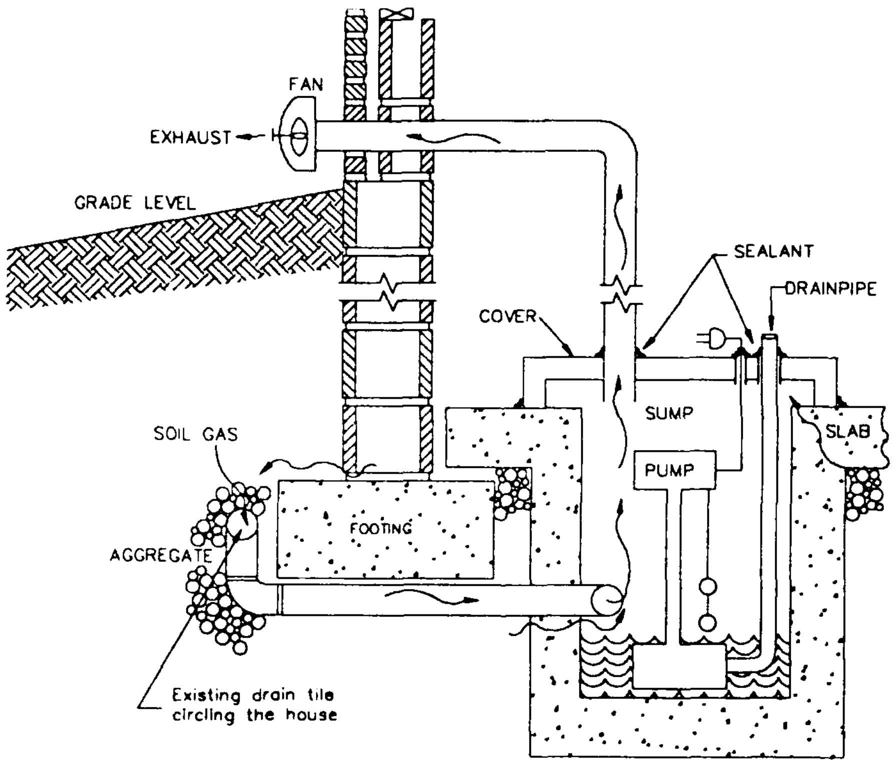

Figure 10. Drain tile ventilation where tile drains to sump. (Source: *Radon Reduction Techniques for Detached Houses, Technical Guidance*, EPA/625/5-86/019 [USEPA, June 1986]).

Maintenance activities for these plumbing components include cleaning the drip pans, making sure drain lines are clear, and running water into the condensate drainpipe to fill the trap.

Air washer systems, evaporative condensers, humidifiers, and cooling towers all have various plumbing components (e.g., strainers, valves, nozzles) that require periodic maintenance. Sections XI through XV of TM5-670 provide further details on maintaining these systems.

Lighting Systems

At least one study has indicated that complaints attributable to IAQ may be related to lighting.[36] It was demonstrated that a change in fluorescent lighting may reduce complaints among office workers in the same way as increased ventilation. While more data are necessary, it is suspected that poor lighting may sensitize individuals to other IAQ deficiencies.

Maintenance of lighting fixtures should be done frequently. Maintenance activities include replacing defective lamps and ballasts, and cleaning the luminaires.

Refrigeration Equipment

Refrigeration systems generally consist of a motor (or engine), compressor, evaporator, condenser, expansion valve, piping, and auxiliary components. In absorption systems the motor-compressor pair is replaced by the generator-absorber. Refrigeration systems are used in air conditioning and other cooling functions such as food storage, water coolers, etc.

Refrigeration systems for HVAC service on Army installations include large central plants, smaller central refrigeration systems in individual buildings, packaged rooftop units, and unitary systems such as window air conditioners and household dehumidifiers. Non-HVAC applications include food lockers, food display cases, household refrigerators, ice makers, and water coolers.

Maintenance of the major components of larger systems is usually performed in the spring before the cooling season starts. Specific guidance on maintenance and repair of the major components of refrigeration and air conditioning systems is provided in Section VIII of TM5-670. Some specific operational parameters that can have direct IAQ impacts include chilled water supply temperature and overall system capacity with respect to maximum loads.

Maintenance of smaller refrigeration equipment located inside a facility can also have IAQ impacts. Systems that may have exposed surfaces with standing water (e.g., ice machines, self-defrosting refrigerators, dehumidifiers) can cause air quality impacts by providing an environment for biological growths. Detailed procedures for ice machine maintenance are provided in Section IV of TM5-670. Maintenance of household refrigerators includes cleaning the condenser coil and the condensate drip pan. Details are provided in Section IV of TM5-670. Similar maintenance is required for household dehumidifiers.

All refrigeration systems located indoors can be sources of VOCs from refrigerant leaks. Generally, any leak large enough to significantly affect IAQ will rapidly render the refrigeration equipment inoperable. When systems require recharging, maintenance should include careful leak inspection and repair to avoid recurrence of refrigerant leakage problems. Testing for refrigerant leaks is discussed in

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[36] M.J. Hodgson.

Section VIII, Paragraph 66, of TM5-670.

Exhaust Hoods and Systems

Local ventilation by hoods and vents minimizes the transport of pollutants from concentrated sources into the remainder of a building space. Examples include kitchen fans, exhaust hoods, bathroom fans, and paint booths. For concentrated sources of pollutants local ventilation can be more efficient than general dilution ventilation of the entire structure. Range hoods can be highly effective in preventing the transport of air contaminants generated by cooking activities into the occupied space.

Maintenance of exhaust hoods and fans consists of fan and filter maintenance. Fan maintenance consists of checking the fan drive for pulley alignment, belt tension, and condition of the belt. Frayed or worn belts should be replaced. Dirt, oil, and grease should be wiped from pulley sheaves and belts. Fan motor bearings should be checked for roughness of movement, and defective bearings should be replaced. Bearings should be lubricated only when required. Motor starting should be observed for proper speed pickup. Dust and dirt should be wiped from the motor housing. Details on filter maintenance are discussed in other parts of this chapter and in TM5-670, Section X.

6 SUMMARY

Poor IAQ can have substantial negative effects on the health and wellbeing of building occupants. These negative effects can increase employee absenteeism and reduce productivity.

Proper building O&M is the single most important factor in providing good IAQ for building occupants. Even buildings of excellent design may have air quality problems if poorly maintained or equipment is operated improperly. For buildings of marginal or poor design, improper O&M practices can result in severe IAQ problems. Additionally, many newer building designs specify reduced ventilation to conserve energy, leaving less margin of error in facility O&M: a minor misadjustment in such systems may cause substantial IAQ problems.

An effective installation IAQ plan and practical O&M procedures that address IAQ concerns can be effective in eliminating the most common occupant complaints related to indoor pollution. The Army Environmental Hygiene Agency and occupational hygienists located at most Army installations are available for assistance in solving difficult IAQ problems.

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APPENDIX A: Indoor Air Quality Questionnaire

Reprinted by permission of ASHRAE from: Rajhans, G.S., "Findings of the Ontario Inter-Ministerial Committee on Indoor Air Quality," *IAQ89 The Human Equation: Health and Comfort*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, 1989.

INDOOR AIR QUALITY SURVEY

This questionnaire is designed to help assess the quality of the indoor environment at ______________________________.

Your answers will remain confidential and they will be used for analyses only.

The questionnaire is collecting data on your working environment, health and lifestyle. Questions are answered by checking the appropriate

box ☑ , circling the appropriate answer glare, or by filling in a blank _________________. There is also space for additional comments.

We are grateful for your help in completing this questionnaire. Please check that you have answered all the questions before sealing the questionnaire in the confidential return envelope.

Hand the sealed envelope to ____________________________________ who will be in the office while you are completing the questionnaire.

Date: ____________________ Time: ____________________

DESCRIPTION OF JOB AND OFFICE

(1) What is your employment status?

- Full time .... ☐
- Part time .... ☐
- Temporary .... ☐
- Other (Specify) ______________________

(2) I have worked in this area since (year) ______, (month) ______, (day) ______.

(3) How many hours per week do you work in this area? ______________ hours.

(4) I am in:

- a closed office ☐
- my own cubicle ☐
- an open area shared with others ☐
- Other ______________________ (Specify)

(5) What is the location of your desk? (Identify on floor map if attached.)

(6) Are you sitting within 3.7 meters (12 feet) of a window?

Yes ☐ No ☐

(7) Can the window be opened?

Yes ☐ No ☐

(8) Within 10 metres (approximately 33 feet) of your work location is there:

(a) typewriter. .... Yes ☐ No ☐
(b) a photocopying machine? .... Yes ☐ No ☐
(c) a keyboard with a video display screen
(e.g. VDT, CRT, data or word processor)? ... Yes ☐ No ☐
(d) a printer .... Yes ☐ No ☐
(e) a teletype or fax machine? .... Yes ☐ No ☐
(f) posting-machine? .... Yes ☐ No ☐
(f) other (specify)? ______________________

(9) For each equipment that you work with, list the number of hours that you use the machine on a typical day.

Equipment	Hours per day
____________________	____________________
____________________	____________________
____________________	____________________

DURING THE PREVIOUS WEEK WHILE WORKING IN YOUR AREA:			
Check "Yes" if symptoms interferred with work.	Circle the symptoms which have given you trouble.	How long did the symptoms last?	Circle when the symptoms are worst?
(10) Nasal symptoms Yes ☐ No ☐	nosebleeds, congestion, sinus problems, sneezing, runny nose, dry nose, other: ____________ (specify)	____________ (hours)	Mon: am pm Tues: am pm Wed: am pm Thurs: am pm Fri: am pm
(11) Throat Symptoms Yes ☐ No ☐	sore throat, dry cough, other: ____________ (specify)	____________ (hours)	Mon: am pm Tues: am pm Wed: am pm Thurs: am pm Fri: am pm
(12) Eye symptoms Yes ☐ No ☐	redness, watering, burning, puffiness, dryness, irritation, blurred vision, other: ____________ (specify)	____________ (hours)	Mon: am pm Tues: am pm Wed: am pm Thurs: am pm Fri: am pm

DURING THE PREVIOUS WEEK WHILE WORKING IN YOUR AREA:			
Check "Yes" if symptoms interferred with work.	Circle the symptoms which have given you trouble.	How long did the symptoms last?	Circle when the symptoms are worst?
	CONTACT LENS WEARERS ONLY		
(13) Problems related to wearing contact lenses Yes ☐ → No ☐	problems with: cleaning, deposits, discomfort, pain, other: ________ (specify)	________ (hours)	Mon: am pm Tues: am pm Wed: am pm Thurs: am pm Fri: am pm
(14) Skin Problems Yes ☐ → No ☐	Dryness, flaking, rash, irritation, other: ________ (specify)	________ (hours)	Mon: am pm Tues: am pm Wed: am pm Thurs: am pm Fri: am pm
(15) Aches and Pains Yes ☐ → No ☐	headache, backache, muscle/joint pain, other: ________ (specify)	________ (hours)	Mon: am pm Tues: am pm Wed: am pm Thurs: am pm Fri: am pm
(16) General Complaints Yes ☐ → No ☐	drowsiness, dizziness, faintness, difficulty in concentration, other: ________ (specify)	________ (hours)	Mon: am pm Tues: am pm Wed: am pm Thurs: am pm Fri: am pm

DURING THE PREVIOUS WEEK WHILE WORKING IN YOUR AREA:			
Check "Yes" if symptoms interferred with work.	Circle the symptoms which have given you trouble.	How long did the symptoms last?	Circle when the symptoms are worst?
(17) Other symptoms Yes ☐ → No ☐ ↓	breathing, digestive, menstrual, other: ________ (specify)	________ (hours)	Mon: am pm Tues: am pm Wed: am pm Thurs: am pm Fri: am pm

(18) Were you ever absent because of any health problem(s) that you feel may have been caused or aggravated by working at your present location?

Yes ☐ → If yes, state the health problem: ____________________

No ☐ ↓

(19) Did you seek medical treatment because of any health problem(s) caused or aggravated by working at your present location?

Yes ☐ No ☐

WORKING ENVIRONMENT: Please record your general assessment of the working environment at your present location.		
Check "Yes" if disturbing	Circle the aspects which are disturbing	Circle when the problems are most disturbing?
(20) Noise Yes ☐ → No ☐ ↓	Noise from: • nearby conversation • lighting • ventilation system • office equipment • other ________ (specify)	Mon: am pm Tues: am pm Wed: am pm Thurs: am pm Fri: am pm
(21) Ventilation Yes ☐ → No ☐ ↓	• temperature • humidity • air movement • other ________ (specify)	Mon: am pm Tues: am pm Wed: am pm Thurs: am pm Fri: am pm
(22) Lighting Yes ☐ → No ☐ ↓	• too bright • not bright enough • glare, flicker • other ________ (specify)	Mon: am pm Tues: am pm Wed: am pm Thurs: am pm Fri: am pm
(23) Others Yes ☐ → No ☐ ↓	Specify: ________ ________ ________	Mon: am pm Tues: am pm Wed: am pm Thurs: am pm Fri: am pm

(24) If there is a smell in your area, how would you describe the smell?

(a) The smell resembles:

- Glue .... ☐
- vinegar .... ☐
- alcohol .... ☐
- ammonia .... ☐
- propane .... ☐
- gasoline .... ☐
- perfume .... ☐
- other ________________ (specify)

(b) It smells:

- smoky .... ☐
- dusty .... ☐
- musty .... ☐
- stale .... ☐
- other ________________ (specify)

(25) In your opinion, where is the smell coming from?

____

____

(26) Do you use any of the following in your work location?

Check appropriate box:

(a) a desk lamp .... ☐

(b) a fan .... ☐

(c) a heater .... ☐

(d) humidifier .... ☐

(e) an ion generator .... ☐

(f) an air cleaner .... ☐

(g) personal care products (e.g. hand cream, hairspray) .... ☐

(Please specify what products) ________________

(h) No items ☐

(27) Have you any control over your work location? Check appropriate box:

(a) ventilation .... ☐

(b) temperature .... ☐

(c) humidity .... ☐

(d) lighting .... ☐

(28) Is smoking allowed in or near your working location?

No ☐ → If No go to question 32.

Yes ☐ ↓

(29) How many cigarettes a day do you smoke at your work location?

None .... ☐

Less than 10 .... ☐

Between 10 and 30 .... ☐

More than 30 .... ☐

(30) Do you smoke any other tobacco product at your work location (e.g. pipe, cigar)?

Yes ☐ → Amount smoked per day:

No ☐

Cigars ________________

Ounces of tobacco ______________

(31) Do other people smoke in your area?

Yes ☐ No ☐

(32) Is there a designated smoking area?

Yes ☐ No ☐

(33) Do you have allergies?

Yes ☐ No ☐

→ Yes you are allergic to: ____________________

(34) Are you taking any prescribed medication for any symptoms you mentioned?

Yes ☐ No ☐

GENERAL INFORMATION

(35) Age (in years) ____________

(36) Sex: Male

Female

ARE THERE ANY FURTHER COMMENTS WHICH YOU WOULD LIKE TO MAKE?

____

____

____

THANK YOU FOR FILLING IN THIS QUESTIONNAIRE

APPENDIX B: Ventilation Standards

Reprinted by permission of ASHRAE from: ASHRAE Standard 62-1989, "Ventilation for Acceptable Indoor Air Quality, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, 1989.

TABLE 2
OUTDOOR AIR REQUIREMENTS FOR VENTILATION*
2.1 COMMERCIAL FACILITIES (offices, stores, shops, hotels, sports facilities)

Application	Estimated Maximum** Occupancy P/1000 ft² or 100 m²	Outdoor Air Requirements cfm/person	L/s·person	cfm/ft²	L/s·m²	Comments
Dry Cleaners, Laundries						Dry-cleaning processes may require more air.
Commercial laundry	10	25	13			
Commercial dry cleaner	30	30	15			
Storage, pick up	30	35	18			
Coin-operated laundries	20	15	8			
Coin-operated dry cleaner	20	15	8			
Food and Beverage Service						
Dining rooms	70	20	10			
Cafeteria, fast food	100	20	10			
Bars, cocktail lounges	100	30	15			Supplementary smoke-removal equipment may be required.
Kitchens (cooking)	20	15	8			Makeup air for hood exhaust may require more ventilating air. The sum of the outdoor air and transfer air of acceptable quality from adjacent spaces shall be sufficient to provide an exhaust rate of not less than 1.5 cfm/ft² (7.5 L/s·m²).
Garages, Repair, Service Stations						
Enclosed parking garage				1.50	7.5	Distribution among people must consider worker location and concentration of running engines; stands where engines are run must incorporate systems for positive engine exhaust withdrawal. Contaminant sensors may be used to control ventilation.
Auto repair rooms				1.50	7.5	
Hotels, Motels, Resorts, Dormitories				cfm/room	L/s·room	Independent of room size.
Bedrooms				30	15	
Living rooms				30	15	
Baths				35	18	Installed capacity for intermittent use.
Lobbies	30	15	8			
Conference rooms	50	20	10			
Assembly rooms	120	15	8			
Dormitory sleeping areas	20	15	8			See also food and beverage services, merchandising, barber and beauty shops, garages.
Gambling casinos	120	30	15			Supplementary smoke-removal equipment may be required.
Offices						
Office space	7	20	10			Some office equipment may require local exhaust.
Reception areas	60	15	8			
Telecommunication centers and data entry areas	60	20	10			
Conference rooms	50	20	10			Supplementary smoke-removal equipment may be required.
Public Spaces				cfm/ft²	L/s·m²	
Corridors and utilities				0.05	0.25	
Public restrooms, cfm/wc or urinal		50	25			Mechanical exhaust with no recirculation is recommended.
Locker and dressing rooms				0.5	2.5	
Smoking lounge	70	60	30			Normally supplied by transfer air, local mechanical exhaust; with no recirculation recommended.
Elevators				1.00	5.0	Normally supplied by transfer air.

* Table 2 prescribes supply rates of acceptable outdoor air required for acceptable indoor air quality. These values have been chosen to control CO_2 and other contaminants with an adequate margin of safety and to account for health variations among people, varied activity levels, and a moderate amount of smoking. Rational of CO_2 control is presented in Appendix D.

**Net occupiable space.

TABLE 2
OUTDOOR AIR REQUIREMENTS FOR VENTILATION* (*Continued*)
2.1 COMMERCIAL FACILITIES (offices, stores, shops, hotels, sports facilities)

Application	Estimated Maximum** Occupancy P/1000 ft² or 100 m²	Outdoor Air Requirements cfm/person	L/s·person	cfm/ft²	L/s·m²	Comments
Retail Stores, Sales Floors, and Show Room Floors						
Basement and street	30			0.30	1.50	
Upper floors	20			0.20	1.00	
Storage rooms	15			0.15	0.75	
Dressing rooms				0.20	1.00	
Malls and arcades	20			0.20	1.00	
Shipping and receiving	10			0.15	0.75	
Warehouses	5			0.05	0.25	
Smoking lounge	70	60	30			Normally supplied by transfer air, local mechanical exhaust; exhaust with no recirculation recommended.
Specialty Shops						
Barber	25	15	8			
Beauty	25	25	13			
Reducing salons	20	15	8			
Florists	8	15	8			Ventilation to optimize plant growth may dictate requirements.
Clothiers, furniture				0.30	1.50	
Hardware, drugs, fabric	8	15	8			
Supermarkets	8	15	8			
Pet shops				1.00	5.00	
Sports and Amusement						
Spectator areas	150	15	8			When internal combustion engines are operated for maintenance of playing surfaces, increased ventilation rates may be required.
Game rooms	70	25	13			
Ice arenas (playing areas)				0.50	2.50	
Swimming pools (pool and deck area)				0.50	2.50	Higher values may be required for humidity control.
Playing floors (gymnasium)	30	20	10			
Ballrooms and discos	100	25	13			
Bowling alleys (seating areas)	70	25	13			
Theaters						Special ventilation will be needed to eliminate special stage effects (e.g., dry ice vapors, mists, etc.)
Ticket booths	60	20	10			
Lobbies	150	20	10			
Auditorium	150	15	8			
Stages, studios	70	15	8			
Transportation						Ventilation within vehicles may require special considerations.
Waiting rooms	100	15	8			
Platforms	100	15	8			
Vehicles	150	15	8			
Workrooms						
Meat processing	10	15	8			Spaces maintained at low temperatures (−10°F to +50°F, or −23°C to +10°C) are not covered by these requirements unless the occupancy is continuous. Ventilation from adjoining spaces is permissible. When the occupancy is intermittent, infiltration will normally exceed the ventilation requirement. (See Ref 18).

* Table 2 prescribes supply rates of acceptable outdoor air required for acceptable indoor air quality. These values have been chosen to control CO_2 and other contaminants with an adequate margin of safety and to account for health variations among people, varied activity levels, and a moderate amount of smoking. Rational of CO_2 control is presented in Appendix D.
**Net occupiable space.

TABLE 2
OUTDOOR AIR REQUIREMENTS FOR VENTILATION* (*Concluded*)

2.1 COMMERCIAL FACILITIES (offices, stores, shops, hotels, sports facilities)

Application	Estimated Maximum** Occupancy P/1000 ft² or 100 m²	Outdoor Air Requirements cfm/ person	L/s· person	cfm/ft²	L/s·m²	Comments
Photo studios	10	15	8			
Darkrooms	10			0.50	2.50	
Pharmacy	20	15	8			
Bank vaults	5	15	8			
Duplicating, printing				0.50	2.50	Installed equipment must incorporate positive exhaust and control (as required) of undesirable contaminants (toxic or otherwise).

2.2 INSTITUTIONAL FACILITIES

Application	Estimated Maximum** Occupancy P/1000 ft² or 100 m²	cfm/ person	L/s· person	cfm/ft²	L/s·m²	Comments
Education						
Classroom	50	15	8			
Laboratories	30	20	10			Special contaminant control systems may be required for processes or functions including laboratory animal occupancy.
Training shop	30	20	10			
Music rooms	50	15	8			
Libraries	20	15	8			
Locker rooms				0.50	2.50	
Corridors				0.10	0.50	
Auditoriums	150	15	8			
Smoking lounges	70	60	30			Normally supplied by transfer air. Local mechanical exhaust with no recirculation recommended.
Hospitals, Nursing and Convalescent Homes						
Patient rooms	10	25	13			Special requirements or codes and pressure relationships may determine minimum ventilation rates and filter efficiency. Procedures generating contaminants may require higher rates.
Medical procedure	20	15	8			
Operating rooms	20	30	15			
Recovery and ICU	20	15	8			
Autopsy rooms				0.50	2.50	Air shall not be recirculated into other spaces.
Physical Therapy	20	15	8			
Correctional Facilities						
Cells	20	20	10			
Dining halls	100	15	8			
Guard stations	40	15	8			

* *Table 2 prescribes supply rates of acceptable outdoor air required for acceptable indoor air quality. These values have been chosen to control CO_2 and other contaminants with an adequate margin of safety and to account for health variations among people, varied activity levels, and a moderate amount of smoking. Rationale for CO_2 control is presented in Appendix D.*

**Net occupiable space.

TABLE 2.3[a]
OUTDOOR REQUIREMENTS FOR VENTILATION OF RESIDENTIAL FACILITIES
(Private Dwellings, Single, Multiple)

Applications	Outdoor Requirements	Comments
Living areas	0.35 air changes per hour but not less than 15 cfm (7.5 L/s) per person	For calculating the air changes per hour, the volume of the living spaces shall include all areas within the conditioned space. The ventilation is normally satisfied by infiltration and natural ventilation. Dwellings with tight enclosures may require supplemental ventilation supply for fuel-burning appliances, including fireplaces and mechanically exhausted appliances. Occupant loading shall be based on the number of bedrooms as follows: first bedroom, two persons; each additional bedroom, one person. Where higher occupant loadings are known, they shall be used.
Kitchens[b]	100 cfm (50 L/s) intermittent or 25 cfm (12 L/s) continuous or openable windows	Installed mechanical exhaust capacity[c]. Climatic conditions may affect choice of the ventilation system.
Baths, Toilets[b]	50 cfm (25 L/s) intermittent or 20 cfm (10 L/s) continuous or openable windows	Installed mechanical exhaust capacity[c]
Garages:		
Separate for each dwelling unit	100 cfm (50 L/s) per car	Normally satisfied by infiltration or natural ventilation
Common for several units	1.5 cfm/ft^2 (7.5 L/s·m^2)	See "Enclosed parking garages," Table 2.1

[a] In using this table, the outdoor air is assumed to be acceptable.
[b] Climatic conditions may affect choice of ventilation option chosen.
[c] The air exhausted from kitchens, bath, and toilet rooms may utilize air supplied through adjacent living areas to compensate for the air exhausted. The air supplied shall meet the requirements of exhaust systems as described in 5.8 and be of sufficient quantities to meet the requirements of this table.

ABBREVIATIONS

ADP	automatic data processing
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BRI	Building-Related Illness
cfm	cubic feet per minute
DEH	Directorate(s) of Engineering and Housing
EPA	U.S. Environmental Protection Agency
ETS	environmental tobacco smoke
HVAC	heating, ventilation, and air conditioning
IAQ	indoor air quality
NIOSH	National Institute for Occupational Safety and Health
O&M	operations and maintenance
PAH	polynuclear aromatic hydrocarbons
pCi/l	picocurie per liter
PCP	pentachlorophenol
ppb	part(s) per billion
ppm	part(s) per million
psi	pounds per square inch
SBS	Sick Building Syndrome
SVOCs	semivolatile organic compounds
TM	technical manual
UST	underground storage tank
VAV	variable air volume
VOC	volatile organic compounds

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322
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